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Lake Erie Nutrient Control

Effectiveness Regarding Assessment in Eastern Basin

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A three-year synoptic monitoring program was conducted on 26 stations from 1973-75. Data generated included major nutrients, temperature structure and oxygen depletion as well as phytoplankton, zooplankton, and benthic macroinvertebrate dynamics. The Basin was separated into five discrete areas based on physico-chemical variables. While anoxia was not observed. there was a hypolimnetic oxygen demand of 0.011 g O_2/m^3/day. The Eastern Basin has remained relatively stable over the past five years with the exception of a decrease in phytoplankton biomass, increase in nitrogen, and a doubling of benthic macroinvertebrates. From a trophic standpoint, the Basin can be classified as mesotrophic. Reductions in algal growth may be in response to pollution abatement, particularly phosphorus.

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IN EASTERN BASIN

by

Great Lakes Laboratory
State University College
Buffalo, New York 14222

Grant No. R802706

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FOREWORD

The eutrophic status of Lake Erie has been a subject of considerable debate by citizens and public officials. The Large Lakes Research Station, Environmental Research Laboratory-Duluth, has been supporting programs to more fully assess and monitor the changes in the state of eutrophication of Lake Erie as pollution control measures are implemented.

This report represents the results of a study on the Eastern Basin of Lake Erie to measure, where possible, the response of the lake to pollution abatement measures.

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ABSTRACT

A three year synoptic monitoring program was conducted on 26 stations in the Eastern Basin of Lake Erie from 1973 to 1975. The data generated include major nutrients, temperature structure, and oxygen depletion as well as phytoplankton, zooplankton and benthic macroinvertebrate dynamics.

The Eastern Basin surface waters were differentiated into five discrete areas with each water mass characterized by a different physio-chemical variable. These areas appeared to be highly influenced by localized inputs into the Basin from specific tributaries such as the Grand River and Twenty Mile Creek as well as such population centers as Erie, Port Colborne and Dunkirk. The nitrogen data in 1974 showed an increase over both 1973 and 1975 levels. There were corresponding increases during 1974 in both phytoplankton and zooplankton biomasses. Anoxic conditions were not observed in the hypolimnetic waters of the Eastern Basin over the study duration and the oxygen demand was calculated to be approximately 0.011 gO_2/m^3/day.

The pelagic biotic variables were in close agreement with findings of earlier investigations. Phytoplankton biomass ranged between 0.3 and 3.7 g/m^3. Chlorophyll-a showed maximum values of 7 mg/m^3 and primary productivity ranged from 16 to 20 mg C/m^3/day. The crustacean zooplankton were similar in both numbers and species encountered to previous work. Furthermore, the ratio of calanoids to cyclopoids plus cladocerans was 0.11, very low on the trophic scale.

The benthic macroinvertebrates displayed an increase in numbers over the past seven years and also showed some species shifts. A mean number of organisms of 8278/m^2 were observed over the three years (1973-1975). Several organisms, especially the oligochaetes, associated with more eutrophic values of the Western and Central Basin have become established in large numbers within the Eastern Basin.

The results of this synoptic survey appear to indicate that in general terms the Eastern Basin has remained relatively stable over the past five years with the exception of a decrease in phytoplankton biomass (1975), an increase in nitrogen (1974) and a doubling in numbers of benthic macroinvertebrates. From a trophic standpoint, the Eastern Basin of Lake Erie can be classified generally as mesotrophic.

This report was submitted in partial fulfillment of Grant Number R-802706 to the Research Foundation, State University of New York, Albany, New York by the U.S. Environmental Protection Agency. Work was completed as of 31 July 1976.

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SECTION 1

INTRODUCTION

The need for more information concerning the lacustrine condition of Lake Erie was indicated by the USFWPCA (1968a, 1968b) and the International Lake Erie Water Pollution Board (1969). Additionally, the International Joint Commission (1975) pointed out the need for more information to describe the ecological status of Lake Erie.

Although many investigations of limnological processes in Lake Erie have been carried out (Herdendorf et al., 1974), comprehensive surveys over several successive years have been infrequent. Furthermore, while Lake Erie in general has been the object of numerous studies, the Eastern Basin of the lake has been neglected to a large extent. In response to concerns about the deteriorating water quality of Lake Erie, the staffs of the Grosse Ile Lab of the U.S. Environmental Protection Agency and the Great Lakes Laboratory (GLL), State University College, Buffalo, New York, planned detailed studies of the Eastern Basin of Lake Erie from 1973 through 1975 which were implemented by the GLL. These studies were funded by the Environmental Protection Agency (EPA) Grant #R-802706. The Eastern Basin surveys were coordinated with similar efforts in the Central and Western Basins of Lake Erie by The Ohio State University and EPA's Grosse Ile Laboratory.

With great variation in physical and chemical parameters within its boundaries, the Eastern Basin is distinct from other Lake Erie regions. It contains the greatest depths and because of land forms and the influence of the Niagara River, the Eastern Basin has a complex system of currents and seiches that influence both water condition and biota in a variety of ways. Results from other research (Burns and Ross, 1972; Burns, personal communication) imply that many of the processes resulting in ecologically critical conditions observed during the 1960's in the Central and Western Basins also were beginning to occur in the Eastern Basin. Concurrently, municipal and industrial discharges have been decreased as part of a lakewide abatement program by the United States and Canada. Therefore, the desirability to obtain information that can quantify the above has increased to the point that the study described in the following pages was initiated.

The objectives of the U.S. Environmental Protection Agency sponsored multi-year project, whose results for 1973 through 1975 for Lake Erie's Eastern Basin, are described here, were as follows:

a. Establish aquatic baseline information and ascertain the trophic status of the Eastern Basin through the collection and analysis of samples for all important chemical, physical, and biological parameters.

b. Quantitatively identify areas of the Eastern Basin that may be experiencing more problems with water quality than other areas.

c. Evaluate the nature and extent of problems associated with over-enrichment and determine the impact of abatement programs within the watershed of the Eastern Basin.

d. Examine the effectiveness of measuring a limited number of biotic and abiotic parameters to evaluate the processes of eutrophication in a large lake.

In order to gather information to address the above, major emphases during this three-year study of the Eastern Basin included determinations of the level of nutrients in the water, the concentrations of oxygen and its depletion in the hypolimnion, and dynamics of the flora and fauna. The Great Lakes Laboratory has attempted to relate biological responses in Lake Erie's Eastern Basin to some of the physical and chemical processes which occur in this aquatic environment, and compare this information to other studies on the lake (i.e. "Lake Erie in the Early Seventies", J. Fish. Res. Bd. Can., 33(3), 1976).

With this in mind, we will first characterize the Eastern Basin of Lake Erie (based on three years of data collection) according to physical and chemical variables. Secondly, we will describe the biological communities of the Basin in respect to the physio-chemical characterization. As part of this description, we will elucidate important biological mechanisms in relation to the total Basin dynamics and identify the relationships involved. Finally, we will discuss the information obtained over the three years in respect to the objectives of this project.

SECTION 2

CONCLUSIONS

The data gathered during the 1973-1975 survey of the mid-lake region of the Lake Erie Eastern Basin (LEEB) by the Great Lakes Laboratory provided a comprehensive limnological baseline which can be used to evaluate the rapidity and direction of future trends in environmental quality. From physical, chemical and biological observations, it was concluded that the Eastern Basin generally can be characterized as mesotrophic. Over the past three to five years there have not been any major changes in water quality with two possible exceptions. A decline in total phytoplankton and particularly the Cyanophyta was noted in 1975 and an increase in nitrogen, especially ammonia, during 1974 was also observed. Contrasting the 1973-1975 quantifications of benthos with those of a 1968 survey, an increase in the forms more commonly associated with eutrophic conditions was noted.

While there were few positive correlations between algal productivity and nutrients (which did not include soluble reactive phosphorus), there were indications that at times nitrogen was limiting. There was a positive relationship between total zooplankton and ammonia.

Higher concentrations of nutrients were observed in areas believed to be influenced by the discharges from specific tributaries, such as the Grand River and Twenty-Mile Creek. Discharges believed to emanate from metropolitan regions, such as Erie, Port Colborne and Greater Buffalo, also had generally negative impacts on the mid-lake water quality of the Eastern Basin. Additionally, nutrients were carried into the Eastern Basin from the Central Basin by entrainment processes.

This study supports the conclusion by previous investigators that the Eastern Basin is the most chemically and physically complex major area of Lake Erie. This report should contribute to a better understanding of the nature and extent of many of the limnological processes within the Eastern Basin.

SECTION 3

RECOMMENDATIONS

While the design and implementation of the 1973-1975 Lake Erie Eastern Basin (LEEB) project were adequate to provide the data necessary to satisfy the objectives of the study, future efforts should be modified in an attempt to answer the questions raised during the initial three years of monitoring as well as to more effectively evaluate the impacts of Canadian and United States pollution abatement programs. Some efforts also did not yield sufficient results to justify their continuation.

It is imperative that the communication among the agencies monitoring the Lake Erie Eastern Basin and its tributaries be continued. An attempt should be made to prepare and exchange data from the previous field effort before the next sampling season is initiated.

A major deficiency in the present LEEB surveillance program is the lack of a comprehensive monitoring effort in the United States nearshore waters. While the Lake Erie Wastewater Management Study of the Corps of Engineers Buffalo District is examining the major U.S. tributaries to the Basin and the Great Lakes Laboratory (GLL) is sampling the mid-lake region of the LEEB, no agency is monitoring the nearshore areas. The latter are the regions most visible to the shorebound human population and the areas most intensely utilized by humans in terms of water supply, waste dilution and dispersion as well as recreation. The nearshore and mid-lake monitoring both cannot be accomplished with financial and other limitations of the GLL's LEEB survey program.

With respect to modifications of the LEEB mid-lake effort, the number of sampling sites should be reduced from 26 to 18 by dropping Stations 2, 5, 7, 10, 12, 17, 22 and 62 (Figure 1). The conditions at the latter eight sites show no difference from other stations in their immediate area and/or do not provide information to evaluate pollution abatement efforts. Thus the remaining stations can be sampled more intensely with adequate replication. The number of Basin-wide cruises, however, should be increased from five to eight in an attempt to reduce the time between cruises to 30 days. Under the present schedule it appeared that biological "peaks" may have been missed several times between 1973 and 1975.

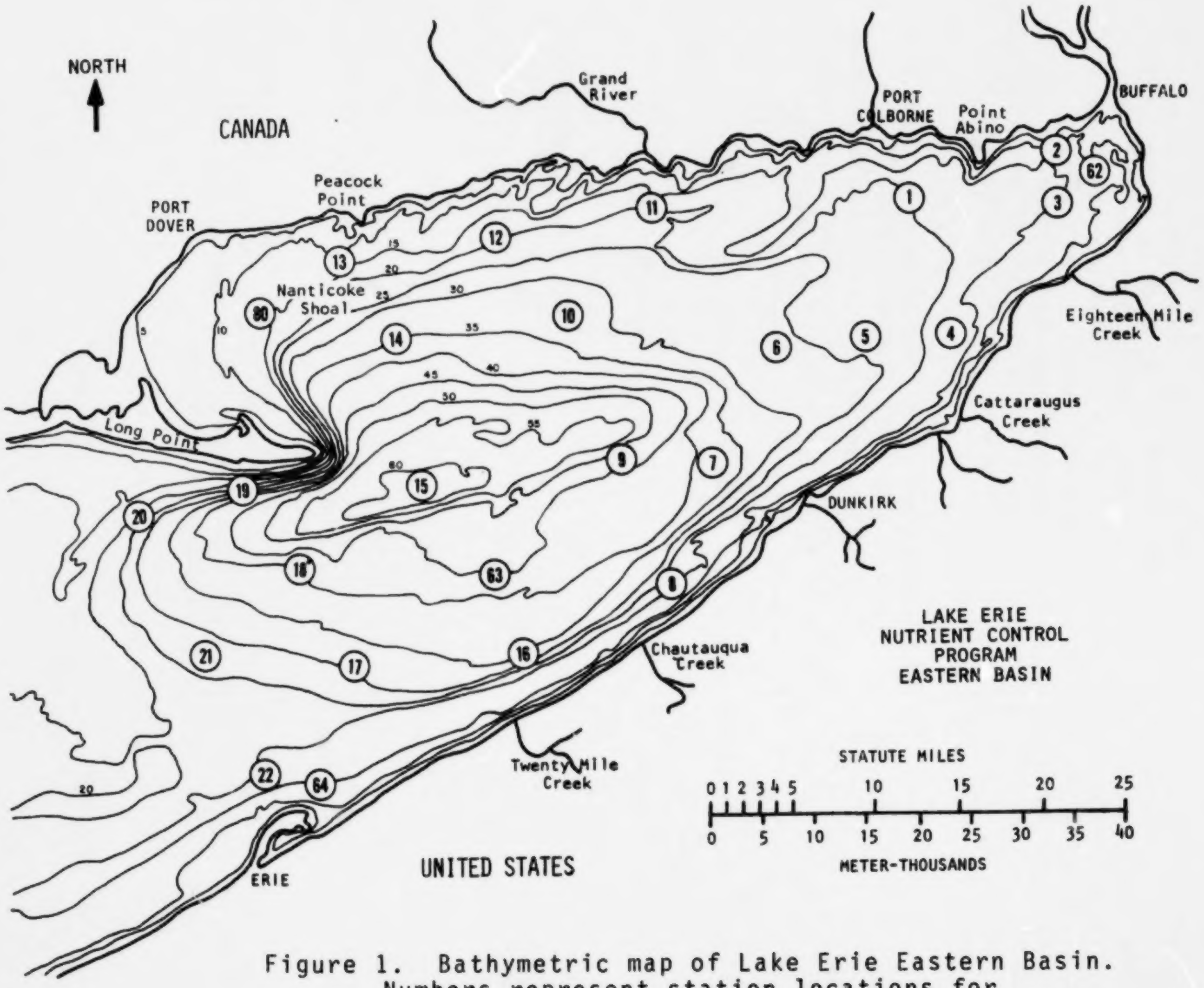
NORTH
CANADA
Grand River
PORT COLBORNE
Point Abino
BUFFALO
Peacock Point
PORT DOVER
Nanticoke Shoal
Long Point
Eighteen Mile Creek
Cattaraugus Creek
DUNKIRK
Chautauqua Creek
Twenty Mile Creek
ERIE
UNITED STATES
LAKE ERIE
NUTRIENT CONTROL
PROGRAM
EASTERN BASIN
STATUTE MILES
0 1 2 3 4 5 10 15 20 25
0 5 10 15 20 25 30 35 40
METER-THOUSANDS
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Figure 1. Bathymetric map of Lake Erie Eastern Basin. Numbers represent station locations for synoptic survey pattern 1973-1975.

With respect to biological parameters, the sampling for phytoplankton and chlorophyll-a should be modified. The surface sample should be replaced by an integrated collection between one and five meters below the surface. This should reduce the problems caused by algal migration within the euphotic zone. An additional sample at a constant depth (7 m) should be collected within the euphotic zone. An attempt should be made to incubate the ^{14}C primary productivity bottles in situ at the collection sites rather than aboard the research vessel. This would require that such productivity measurements be limited to stations from which the bottles could readily be retrieved after four hours by a smaller craft. This approach would add extra flexibility to our monthly sampling schedule.

The 1973-1975 benthos collections, which were gathered at each station during 1-3 cruises per year, have provided some valuable baseline data. With such a sporadic sampling interval, however, some bottom organisms that are only present seasonally could be missed and community succession would be impossible to follow. Therefore, the number of benthos collection stations should be reduced to ten (Stations 3, 6, 11, 14, 15, 16, 19, 21, 64 and 80), but these should be sampled in triplicate four times per year (one in spring, two in summer, one in fall). To fully compliment the benthic data, particle size and total organic carbon should also be measured on these sediments.

An effort should be made to obtain a pH and conductivity profile at each sampling site in addition to the dissolved oxygen-temperature profiles. The former could provide more information on the nature and distribution of chemoclines which are present in the Basin.

With respect to chemical parameters, particulate inorganic carbon should be dropped because of the uniformity of the values obtained. Soluble reactive phosphorus as well as silica and total inorganic carbon should be quantified because of the importance of those chemicals to primary productivity.

In view of the preservation difficulties concerning some forms of nitrogen and phosphorus, consideration should be given to installing an autoanalyzer on the research vessel to facilitate more rapid quantification of such parameters.

SECTION 4

METHODS

DATA COLLECTION

In 1973, 25 sampling stations were established in the Eastern Basin of Lake Erie in an attempt to comprehensively characterize this region. In 1974 an additional station (Station 80) was added to the sampling schedule to include the area of Long Point Bay. The location of the 26 Eastern Basin stations is shown on the bathymetric map in Figure 1. One of the reasons for selecting these sampling sites, besides giving synoptic coverage of the Eastern Basin, was to maintain an equal division between inshore (<25 m) and offshore (>25 m) sampling sites.

During the three year project period a total of 26 synoptic cruises were conducted; eight in 1973, thirteen in 1974 and five in 1975. These cruises were systematically divided to cover the three seasons of spring, summer, and fall. An attempt was made in the scheduling to conduct comparable cruises each of the three years. This was not always possible, however, because of weather and/or mechanical difficulties. Over the three years, there were 15 cruises that could be compared (Table 1). These will receive the major focus of this report.

Sample collection techniques and methods of sample analysis are thoroughly described in each of the annual reports (Great Lakes Laboratory, 1974; 1975; 1976) for the project. With the increase in efficiency and expertise of our laboratory and changes in EPA-improved procedures and techniques, several methods of sample collection and analysis were changed over the course of the study. These will be described briefly.

Modifications in the field sampling procedure did not involve changes in instrumentation. Procedures such as primary productivity incubation (light box incubations - 2 hr) and dissolved oxygen determination, however, were modified to make our field operation more efficient.

In the laboratory, the nitrogen compounds (NO_3, NH_3, and Org-N) were determined by manual methods of Kjeldahl digestion for NH_3 and Org-N and the Brucine Method for NO_3 in 1973 and 1974. In 1975, GLL changed to the use of the Technicon AutoAnalyzer and

Table 1. COMPARABLE LAKE ERIE EASTERN BASIN CRUISE DATES 1973-1975

	1973	1974	1975
SPRING		21 May - 1 June	9-12 April
SUMMER	4-11 July	18-22 June	2-5 June
	31 July - 6 Aug	26-30 July	25-29 July
FALL	1-4 October	6-9 September	15-18 September
	8-11 October	23-27 October	7-21 December
		19 Nov - 5 Dec	

determined NO_3 using the cadmium reduction method (Technicon Industrial Method #158-71W). Ammonia was determined on the AutoAnalyzer by reaction with alkaline phenolhyperchlorite (Technicon Industrial Method #154-71W) and Org-N with the same reaction after Kjeldahl digestion. Dissolved and total phosphorus were determined by the manual Ascorbic Acid Method with persulfate digestion in 1973 and 1974. In 1975 total and dissolved phosphorus were measured on the AutoAnalyzer. The Ascorbic Acid Method was used on both filtered and unfiltered samples after potassium sulfate digestion (modification of Technicon Industrial Method #155-71W). Particulate inorganic and organic carbon (PIC and POC, respectively) were measured on the Coleman Carbon-Hydrogen Analyzer in 1973. Filtered and unfiltered, acidified and unacidified samples collected in 1974 and 1975 were analyzed on the Beckman Model 915 Carbon Analyzer. POC and PIC values were determined by difference.

Methodological equivalency experiments were conducted for the phosphorus, nitrogen and carbon analyses to verify the comparison of data generated using "wet" vs. automated methods. These experiments showed that all phosphorus analyses and carbon analyses using the different methods were not statistically different at the 0.05 level with N=25 at concentrations of 15 μg P/l, 4.0 mg C/l for PIC and 0.8 mg C/l for POC. With both the phosphorus and carbon, however, the automated analyses markedly increased sensitivity with slightly better precision and accuracy.

With respect to the nitrogen series, NO_3-N analyses also showed no statistical difference at the 0.05 level with N=25 at a concentration of 0.12 mg N/l. Again increased sensitivity with better precision and accuracy was found. The results of Org-N comparisons between the two methods were statistically different at the 0.10 level with N=25 at a concentration of 0.35 mg N/l. Automated analysis did, however, increase sensitivity, accuracy and precision. It was believed that this slight decrease in comparability in the Org-N results over the three years was negligible. Comparison of NH_3-N data from the "wet" vs. automated analyses were statistically different at the 0.12 level with N=25 at a concentration of 0.05 mg N/l. Again sensitivity, accuracy and precision were markedly improved. Data comparisons were made for 1973 through 1975 and are believed to be valid but must be viewed in light of the lower comparabilities found.

Like the field operation, the methodology employed in the quantification of phytoplankton, zooplankton and benthos did not experience any real changes in procedure. However, with experience as well as advances in the taxonomy and keys, organisms were identified to more precise levels of classification.

DATA ANALYSIS

Selected chemical and physical data collected from all Eastern Basin stations over the three years were used in a discriminant analysis routine to statistically distinguish between different areas within the Eastern Basin and characterize these environments. The discriminating variables used in the analysis and their units are listed in Table 2. The objective of our use of discriminant analysis was to combine these variables in some fashion so that the sampling stations would fall into groups (areas of the Basin) which were as statistically distinct from one another as possible.

Stepwise calculations were made in order to determine which variables were significant in contributing discriminant power to the areas of the Basin ultimately proved to be different. All computations were made to a significance level of $P \leqslant 0.05$. The analyses were done on the State University of New York (SUNY) IBM 360 Computer using the Statistical Package for Social Scientists (SPSS) Discriminant Package (Nie et al., 1970).

The results of these analyses provided several tools for the interpretation of the data. Among these were the statistical tests for measuring the success with which the variables actually discriminated when combined into discriminant functions. Furthermore, since the discriminant functions obtained could be thought of as the axes of a geometric space, they were used to study the spatial relationships among the groups of stations. Most importantly, however, the discriminant functions and their weighting coefficients served to identify the variables which contributed the most to differentiation among the respective groupings of stations.

Selected physical, chemical and biological data from all stations for the three years were used in correlation and stepwise multiple regression analyses to determine the kind and degree of relationship existing between variables. This hierarchial method provided the framework for the identification of relevant associations. The biological variables considered and their units are listed in Table 3.

Stepwise calculations were made with independent variables entering the regression in order of decreasing importance. Computations were done on the SUNY IBM 360 Computer using the SPSS Regression Package (Nie et al., 1970). All computations were made to a significance of $P < 0.01$. An attempt was made to elucidate mechanisms and define relationships between variables; thus a linear method was used so that results could be justified on the knowledge of biological mechanisms or comparability with general biological principles.

Analyses were performed on the data obtained from benthic collections over the three years using ordination of species based on principal components analysis (Orloci, 1966). This technique provided a means of summarizing the raw data of species lists from the 26 stations and objectively arranging the different

Table 2. FACTORS CONSIDERED IN DISCRIMINANT ANALYSIS OF CHEMICAL AND PHYSICAL PARAMETERS OF LAKE ERIE

Variable	Abbreviation	Units
pH	pH	standard units
Conductivity	COND	µmoles/cm
Dissolved Oxygen	DO	mg/l
Temperature	TEMP	°C
Chlorophyll	CHL	mg/m^3
Secchi Disc	SD	m
Nitrate (NO_3^-)	NO	µg N/l
Ammonia (NH_3^-)	NH	µg N/l
Total Nitrogen	TN	µg N/l
Total Phosphorus	TP	µg P/l
Dissolved Phosphorus	DP	µg P/l

Table 3. BIOLOGICAL FACTORS CONSIDERED IN REGRESSION ANALYSES

Variable	Abbreviation	Units
Total Phytoplankton Biomass	PHYTO	mg/m^3
Chlorophyta Biomass	GREEN	mg/m^3
Pyrrhophyta Biomass	DINO	mg/m^3
Flagellate Biomass	FLAG	mg/m^3
Chrysophyta Biomass	DIATOM	mg/m^3
Cyanophyta Biomass	BLUG	mg/m^3
Cladocera Numbers	CLAD	$\#/m^3$
Calanoida Numbers	CALA	$\#/m^3$
Cyclopoida Numbers	CYCLO	$\#/m^3$

communities (grouping of similar stations) as points in a graphical display. The assumption of this technique was that the position of the points or cluster of points along the graphical axes may reflect community relationships. Assigning meaning to the axes of the ordination graph, or identifying major community groups is subjective (Lambert and Dale, 1964) although some state that the misinterpretation of the data is small (Cattell, 1965). To remove the subjective nature from this technique, discriminant analysis calculations were made on results of the community ordination (3 coordinates) to determine separation of the points in space. This resulted in groupings of stations classified according to certain benthic community types in the Eastern Basin. The community ordination was done using a modified version of a FORTRAN program developed by D. Young of the Ohio State University (personal communication) and performed on the SUNY IBM 360 Computer.

SECTION 5

RESULTS

CHARACTERIZING THE ENVIRONMENT

Lake Erie's Eastern Basin exhibits the characteristics of a monomictic (K. Stewart, personal communication) mesotrophic lake in the temperate zone. During the 1973, 1974 and 1975 sampling seasons the thermocline formed near the surface and progressively moved deeper during the summer and early fall to maximum depths of greater than 30 m in some instances. Although the GLL never sampled during winter periods, there was an ice cover over the Eastern Basin each of the three sampling years. Stewart found a lack of inverse stratification in 1972 throughout the entire lake. Very little light penetrated deeper than approximately 14 m (2.5 times the maximum Secchi disc measurements - Larson, 1972) during the year. Profiles of pH and specific conductance were clinograde during summer stratification and vertically uniform during spring and fall mixing (Great Lakes Lab, 1974; 1975; 1976).

Dissolved and total phosphorus exhibited inverse clinograde profiles during stratification and relative uniformity after turnover; nitrate and ammonia also followed this trend, as a rule. The organic nitrogen profiles, however, were clinograde during stratification and uniform during mixing. Dissolved oxygen concentrations were negatively heterograde during stratification and uniform during mixing (Great Lakes Lab, 1974; 1975; 1976).

Data were first analyzed to characterize the epilimnetic waters of the Basin occupied on each cruise (Figure 1) over the three years. Comparisons of samples taken from a meter below the surface (S-1 m) with mid-epilimnetic samples showed no significant difference ($P \leq 0.05$). Therefore, 1 m sample data were used to represent the epilimnetic waters of the Basin.

The diagrams in Figures 2-3 give the distribution of some of the phosphorus forms in the Eastern Basin. Mean total phosphorus for each station over the year (Figure 2) shows a progressive decrease in the nearshore waters from 1973 to 1975 at the western end of the Basin and conversely an increase in the offshore waters, especially from 1974 to 1975. The eastern end of the Basin shows a progressive decrease in total phosphorus similar to the nearshore waters further west. Dissolved

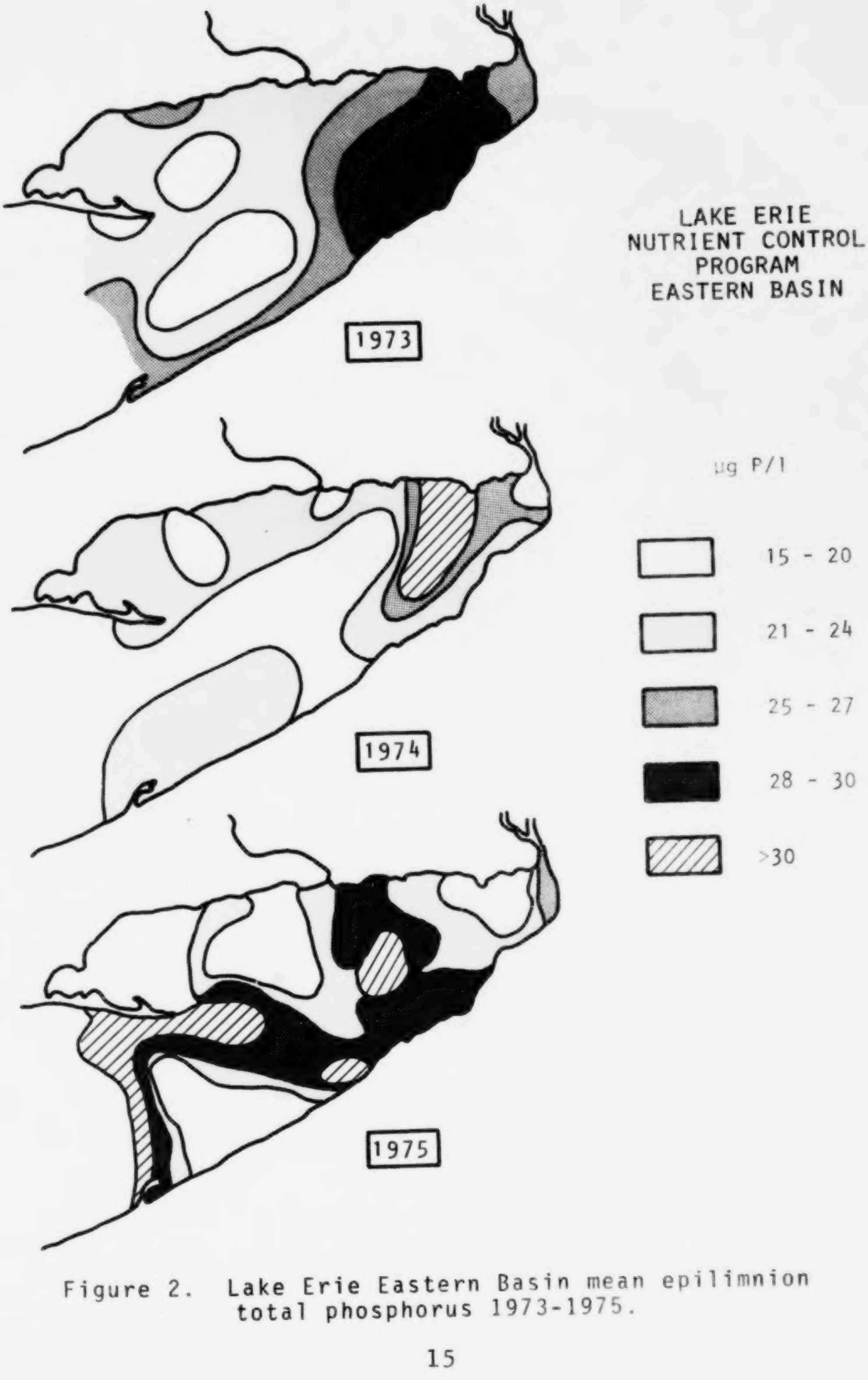

LAKE ERIE
NUTRIENT CONTROL
PROGRAM
EASTERN BASIN
1973
1974
1975
μg P/l
15 - 20
21 - 24
25 - 27
28 - 30
>30

Figure 2. Lake Erie Eastern Basin mean epilimnion total phosphorus 1973-1975.

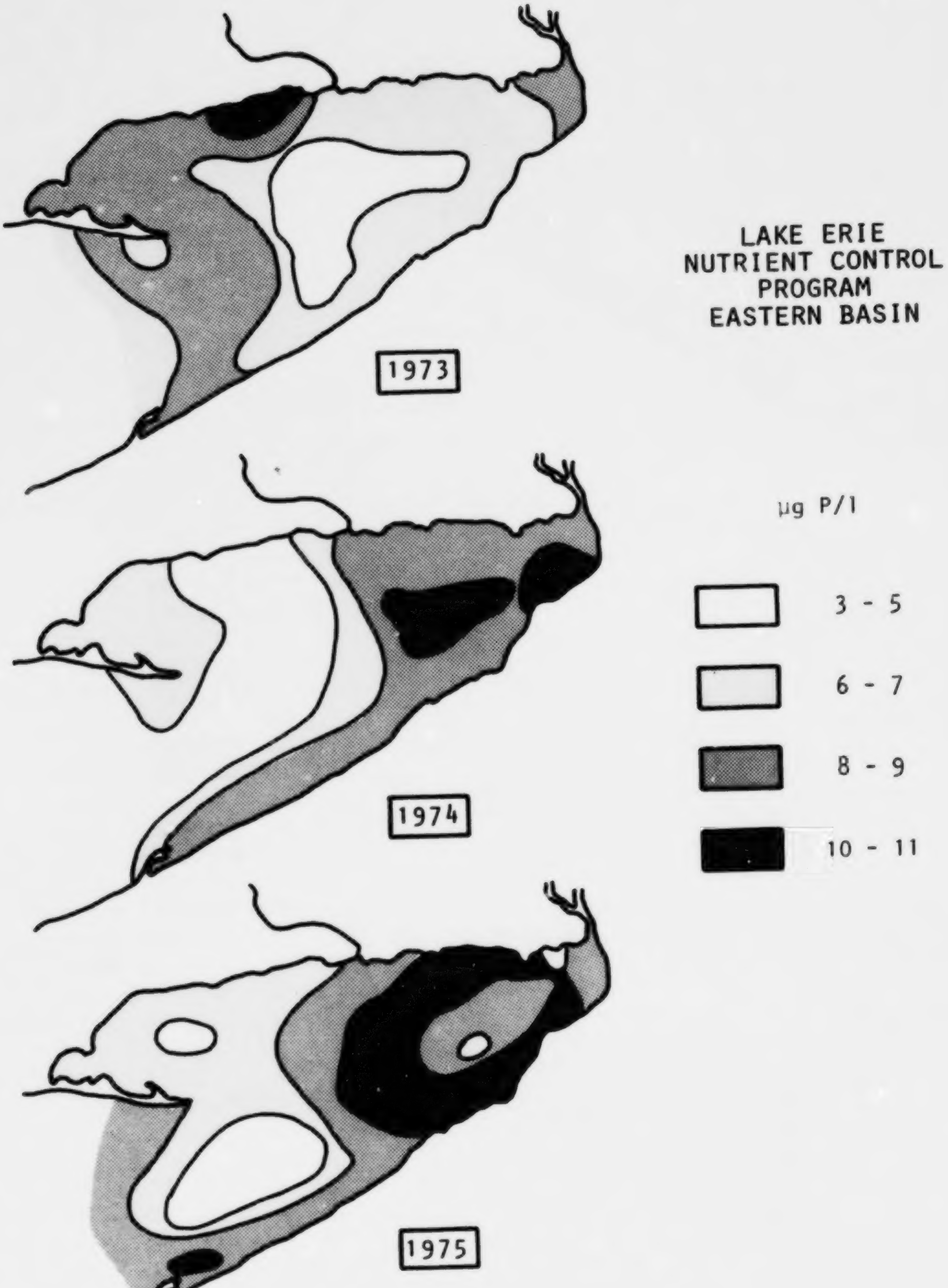

LAKE ERIE
NUTRIENT CONTROL
PROGRAM
EASTERN BASIN
1973
1974
1975
µg P/l
3 - 5
6 - 7
8 - 9
10 - 11

Figure 3. Lake Erie Eastern Basin mean epilimnion dissolved phosphorus 1973-1975.

phosphorus (Figure 3), the more important of the two phosphorus forms with respect to utilization by phytoplankton, shows a definite increase over the three years, Basin-wide. In 1974 there was a decrease of approximately 4 μg P/l in the western part of the Basin. This was short lived showing an increase in 1975, near 1973 levels. The eastern end of the Basin displayed a definite increase over the entire three years with most waters showing 5-7 μg P/l in 1973, 7-9 μg P/l in 1974 and 9-11 μg P/l in 1975.

As shown in Table 4, there is no significant change in total Basin means over the three years for total phosphorus, while the dissolved phosphorus increases from a mean of 4.3 μg P/l in 1973 to a Basin mean of 7.4 μg P/l in 1975. The seasonal concentrations for total phosphorus show the general trend of a spring peak (1975) with a decrease to mid-summer when a slight peak appears again leading to a fall minimum. Dissolved phosphorus, on the other hand, displays minimal values during the early spring (1975) and summer and higher values during the late spring and fall seasons.

According to the diagrams of Figures 4-6, the major nitrogenous compounds of the Eastern Basin epilimnetic waters reach maximum concentrations in 1974. Nitrate concentrations (Figure 4) generally range less than 150 μg N/l over most of the Basin in 1973. In 1975 these concentrations are very similar except for the southern shore of the Basin which displays nitrate concentrations in the range of 250 μg N/l off the shores of Dunkirk and Barcelona. On the contrary, 1974 concentrations are much higher over the entire Basin. As a rule the ammonia (Figure 5) and total nitrogen (Figure 6) concentrations follow the same general pattern of distribution as the nitrate values, with relatively low values in 1973 and 1975 compared with 1974. The ammonia and total nitrogen show even lower concentrations in 1975 than in 1973 but the most western end of the Basin shows some influences from the Central Basin during 1975 because there are high increases in concentrations of total nitrogen not reflected in either nitrate or ammonia. These higher values of total nitrogen reflect increases in organic nitrogen for 1975 in this area, possibly caused by inflows of rich organic waters from the Central Basin and upwelling along the northern shore with subsequent resuspension of bottom materials.

Table 4 further reflects the drastic change in 1974 compared to 1973 or 1975 for the different nitrogen compounds. The total Basin means for the year for total nitrogen, nitrate and ammonia are very different in 1974 from either of the other two years. Nitrate, the most quantitatively available form of nitrogen for biotic processes, shows the general trend of high values in the spring and then decreases throughout the remainder of the year to minimum values in the fall. An unusual trend is seen with the ratios of total nitrogen with ammonia and nitrate

Table 4. MEANS AND STANDARD DEVIATIONS FOR THE SEASONAL AND ANNUAL CONCENTRATIONS OF TOTAL PHOSPHORUS, DISSOLVED PHOSPHORUS, TOTAL NITROGEN, NITRATE-NITRITE, AMMONIA, PIC AND POC IN THE EASTERN BASIN OF LAKE ERIE 1973-1975.

	Total P		Dissolved P		Total N		Nitrate-Nitrite		Ammonia		PIC		POC	
	µg/1										mg/1			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1973														
Summer	47.0	± 31.0	2.6	± 2.7	468	± 156	87.6	± 75.8	86.7	± 88.9	3.05	± 0.8	0.58	± 0.4
Fall	15.1	± 6.6	5.9	± 3.3	316	± 131	73.6	± 65.3	61.7	± 48.9	2.70	± 0.9	0.66	± 0.9
Annual	30.6	± 27.3	4.3	± 3.4	390	± 162	80.4	± 70.6	73.8	± 71.8	2.88	± 0.8	0.62	± 0.6
1974														
Spring	21.5	± 12.6	9.7	± 6.7	800	± 316	319	± 234	148	± 147	3.95	± 1.1	0.48	± 0.2
Summer	27.3	± 49.2	7.0	± 9.8	633	± 252	152	± 135	234	± 187	3.08	± 1.4	0.54	± 0.6
Fall	13.6	± 14.7	4.7	± 5.8	552	± 165	166	± 135	178	± 126	1.67	± 1.4	2.57	± 1.1
Annual	22.3	± 37.7	6.7	± 8.5	637	± 252	185	± 167	203	± 167	2.97	± 1.5	1.20	± 1.1
1975														
Spring	38.1	± 37.9	6.6	± 5.3	310	± 141	180	± 117	42.0	± 26.5	2.02	± 2.5	1.25	± 2.4
Summer	23.8	± 35.5	7.5	± 6.4	632	± 890	97.3	± 96.1	23.2	± 26.9	2.84	± 1.9	1.04	± 1.3
Fall	20.9	± 11.9	8.1	± 4.5	365	± 161	51.9	± 59.7	32.1	± 33.2	2.90	± 1.6	0.64	± 0.8
Annual	25.2	± 29.7	7.4	± 5.4	469	± 587	100	± 101	38.1	± 52.1	2.68	± 1.9	0.93	± 1.5

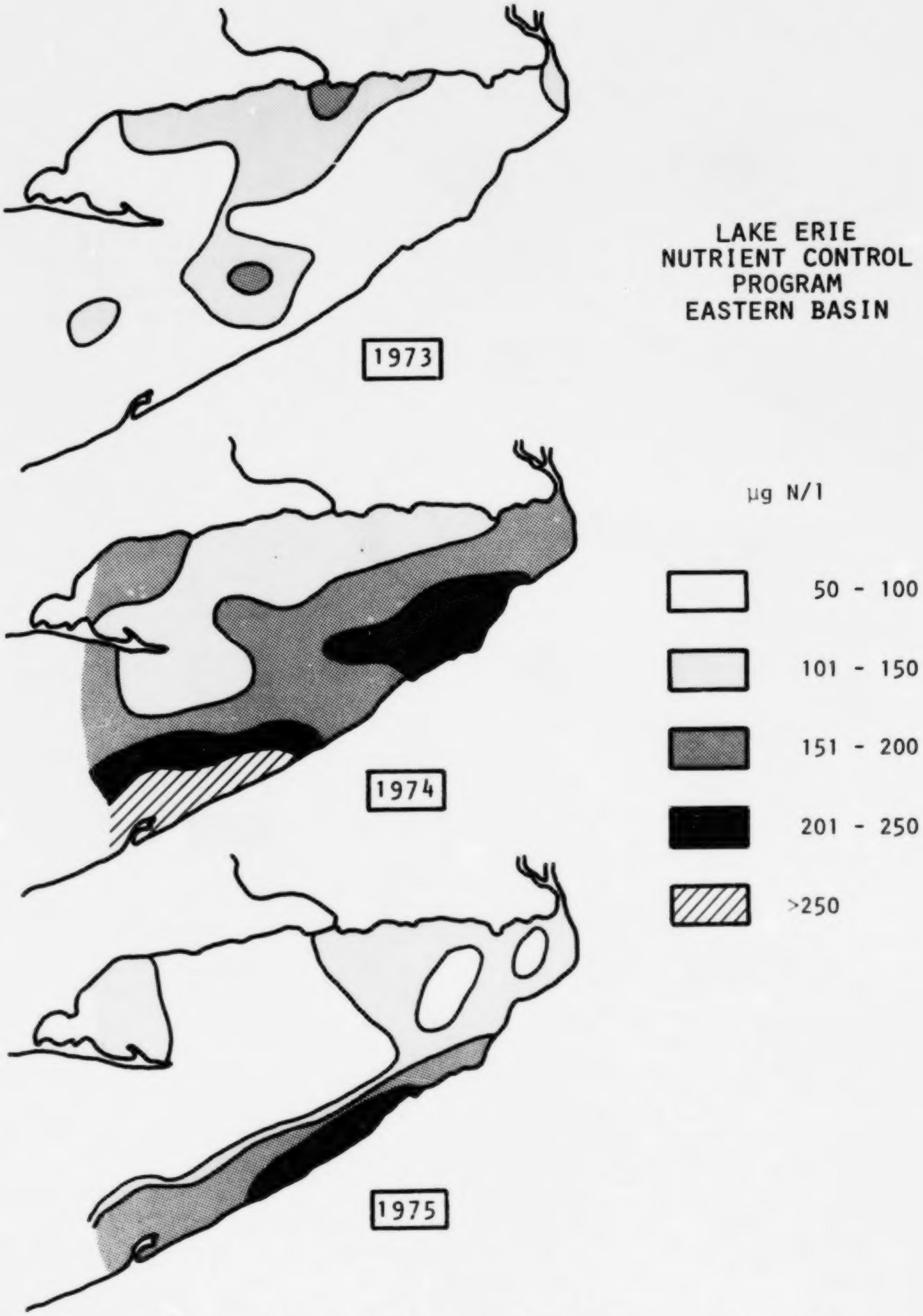

LAKE ERIE
NUTRIENT CONTROL
PROGRAM
EASTERN BASIN
1973
1974
1975
µg N/1
50 - 100
101 - 150
151 - 200
201 - 250
>250

Figure 4. Lake Erie Eastern Basin mean epilimnion nitrate-nitrite 1973-1975.

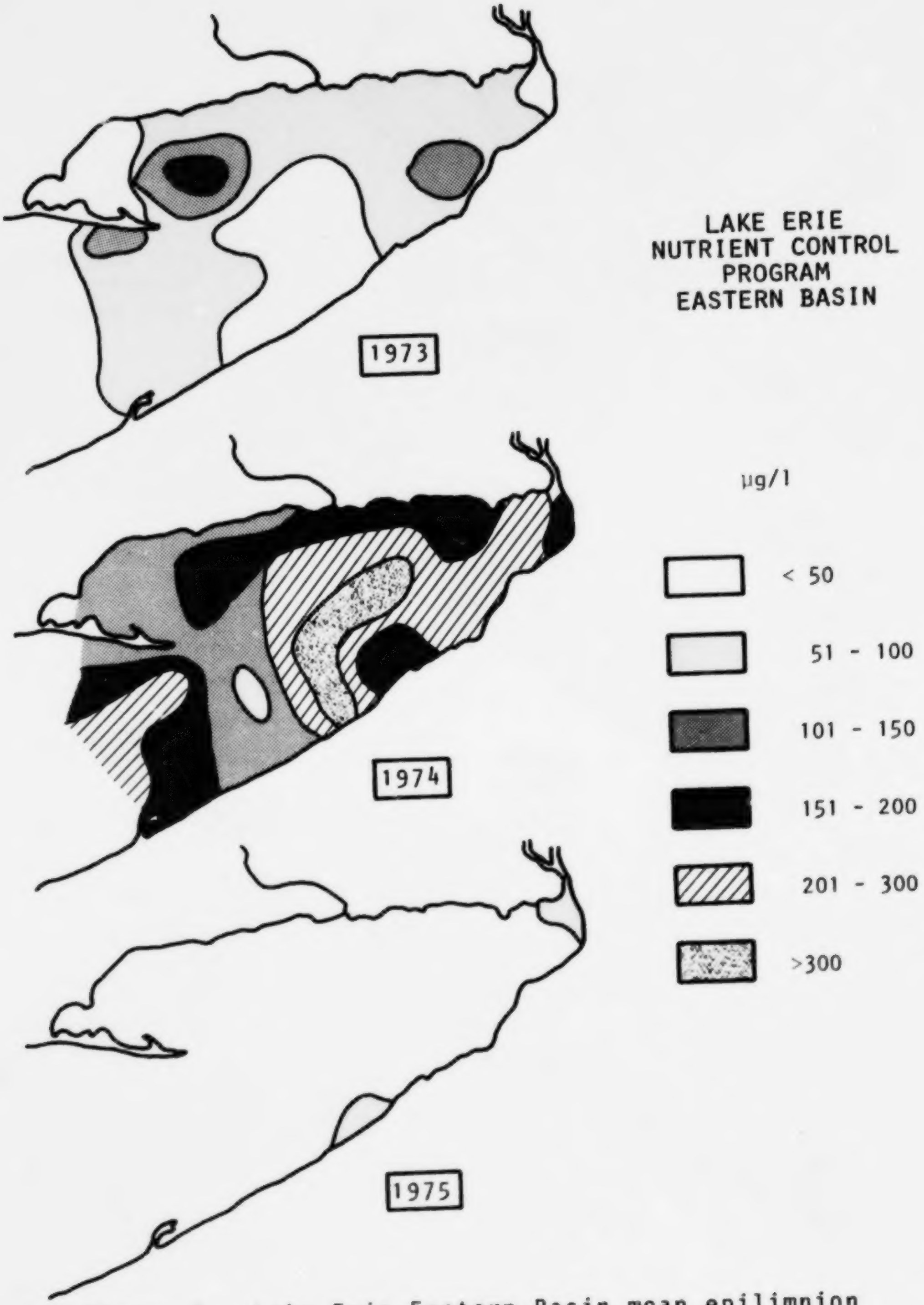

LAKE ERIE
NUTRIENT CONTROL
PROGRAM
EASTERN BASIN
1973
1974
1975
µg/1
< 50
51 - 100
101 - 150
151 - 200
201 - 300
>300

Figure 5. Lake Erie Eastern Basin mean epilimnion ammonia 1973-1975.

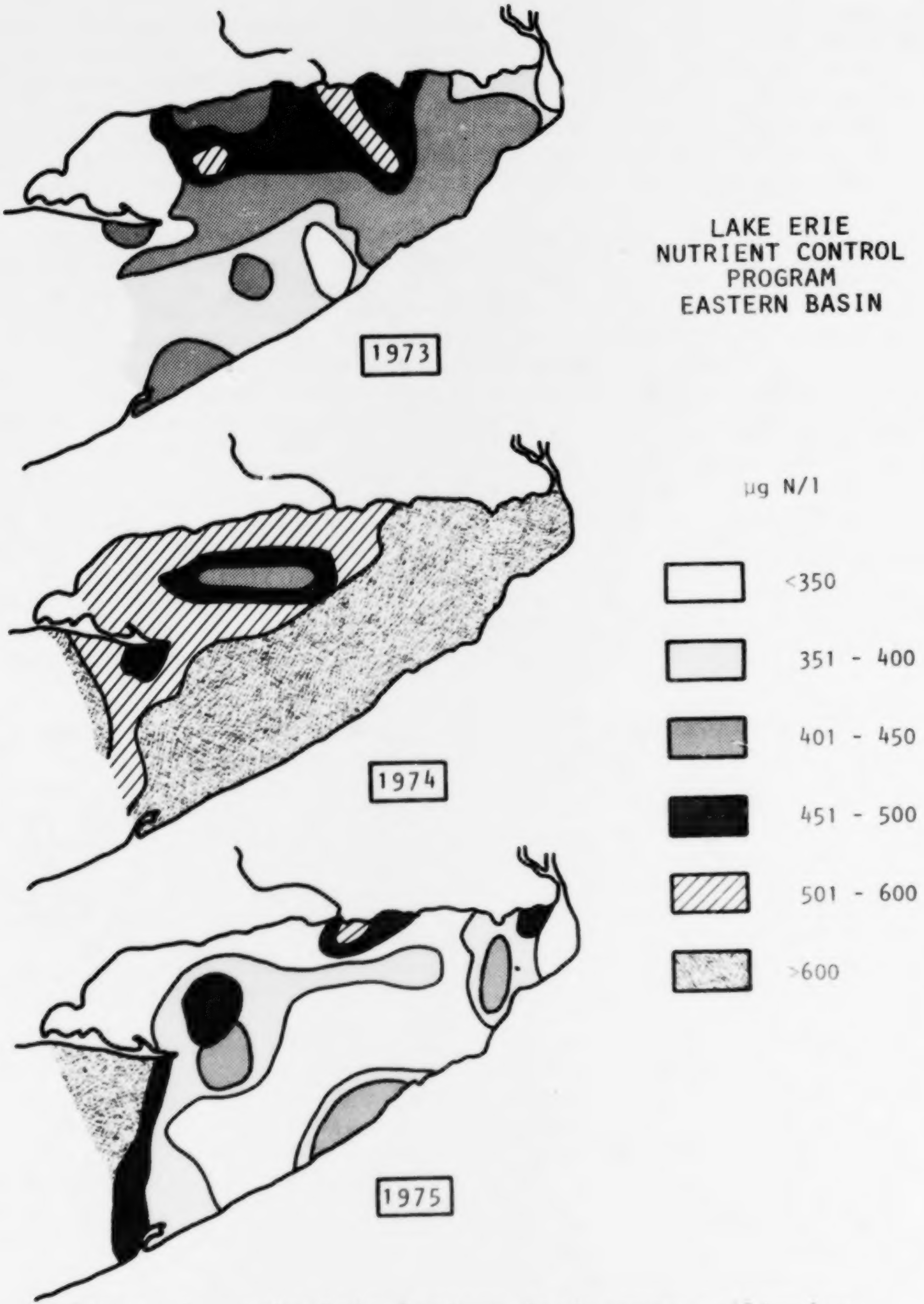

LAKE ERIE
NUTRIENT CONTROL
PROGRAM
EASTERN BASIN
1973
1974
1975
μg N/1
<350
351 - 400
401 - 450
451 - 500
501 - 600
>600

Figure 6. Lake Erie Eastern Basin mean epilimnion total nitrogen 1973-1975.

concentrations over the three years. Nitrate and ammonia represent less than 50% of total nitrogen during most cruises in 1973 and 1975, implying that organic nitrogen was a large component of total nitrogen during these years. In 1974, however, ammonia and nitrate concentrations represent much more of the total nitrogen concentrations, indicating relatively less organic nitrogen during this sampling year in relation to the other nitrogen forms.

The particulate organic carbon (POC) observed in the surface waters of the Eastern Basin over the study duration was relatively similar from year to year except for an increase seen during the fall of 1974 (Table 4) which directly affected the total mean for that year. Annual trends (Figure 7) illustrated that the shallower stations of the Basin displayed higher mean values of POC and the deeper stations were characterized by lower POC values. In 1975 the trend was higher concentrations observed on the mid-lake stations and decreases in POC moving toward each shore of the Basin. Furthermore, the 1975 cruises indicated that entrainment from the Central Basin may have occurred along the two shores entering the Eastern Basin. This was especially apparent during the summer cruises (Great Lakes Lab, 1976) where the western stations of the Basin showed definite increases. The vertical profiles for POC (Great Lakes Lab, 1975; 1976) indicated that there were numerous periods of mixing of the water column (uniform POC) in 1974 with definite chemocline present during 1975.

The Basin trends for pH (Figure 8) were not very different over the three years except in isolated areas of the Basin. Because of this lack of difference between locations, pH was a definite factor contributing to heterogeneity when a very small alteration occurred during the sampling cruises. The general three year trend was a decrease in pH from 8.6 in 1973 to 8.4 in 1975 over much of the Basin. pH at the eastern end of the Basin was generally higher except for the water mass off Port Colborne which showed a significantly lower pH in 1975 compared to the other two years and the other areas of the lake. This may imply a specific event occurred that didn't take place in 1973 or 1974.

The particulate inorganic carbon (PIC) showed annual means that were similar between 1973 and 1974 (Table 4) with a slight decrease in 1975. When higher values were observed during the study period, they were generally associated with northwestern stations on the Canadian side of the Basin. In 1975 the seasonal PIC values appeared to correspond to the pH trends of low spring values and higher summer and fall values (Great Lakes Lab, 1976). This is an expected trend with the carbonate formation resulting from high pH.

An important aspect of the data analysis was to observe the constancy of water quality for each individual station from year to year. Therefore, individual station water quality was

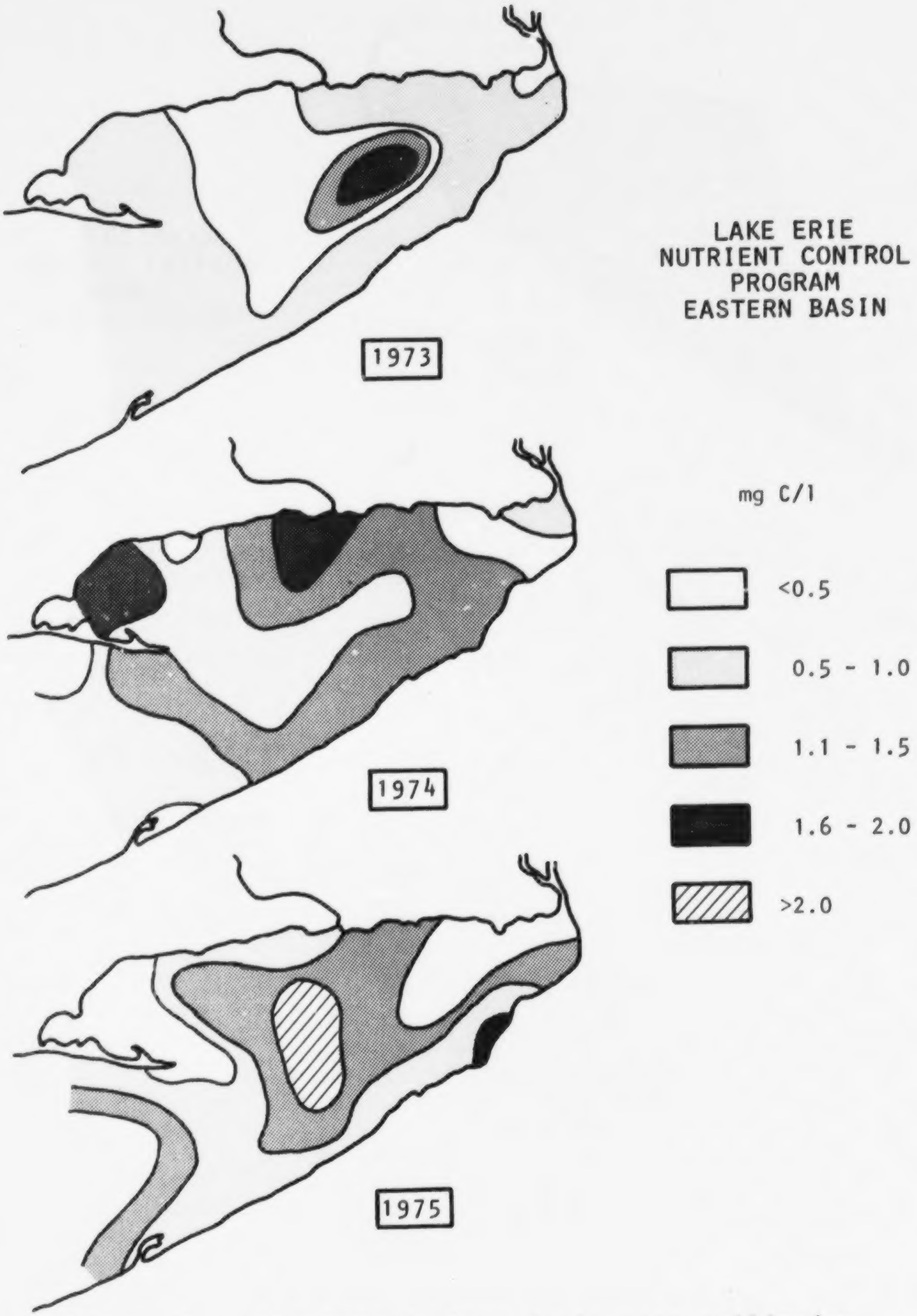

LAKE ERIE
NUTRIENT CONTROL
PROGRAM
EASTERN BASIN
1973
1974
1975
mg C/l
<0.5
0.5 - 1.0
1.1 - 1.5
1.6 - 2.0
>2.0

Figure 7. Lake Erie Eastern Basin mean epilimnion particulate organic carbon 1973-1975.

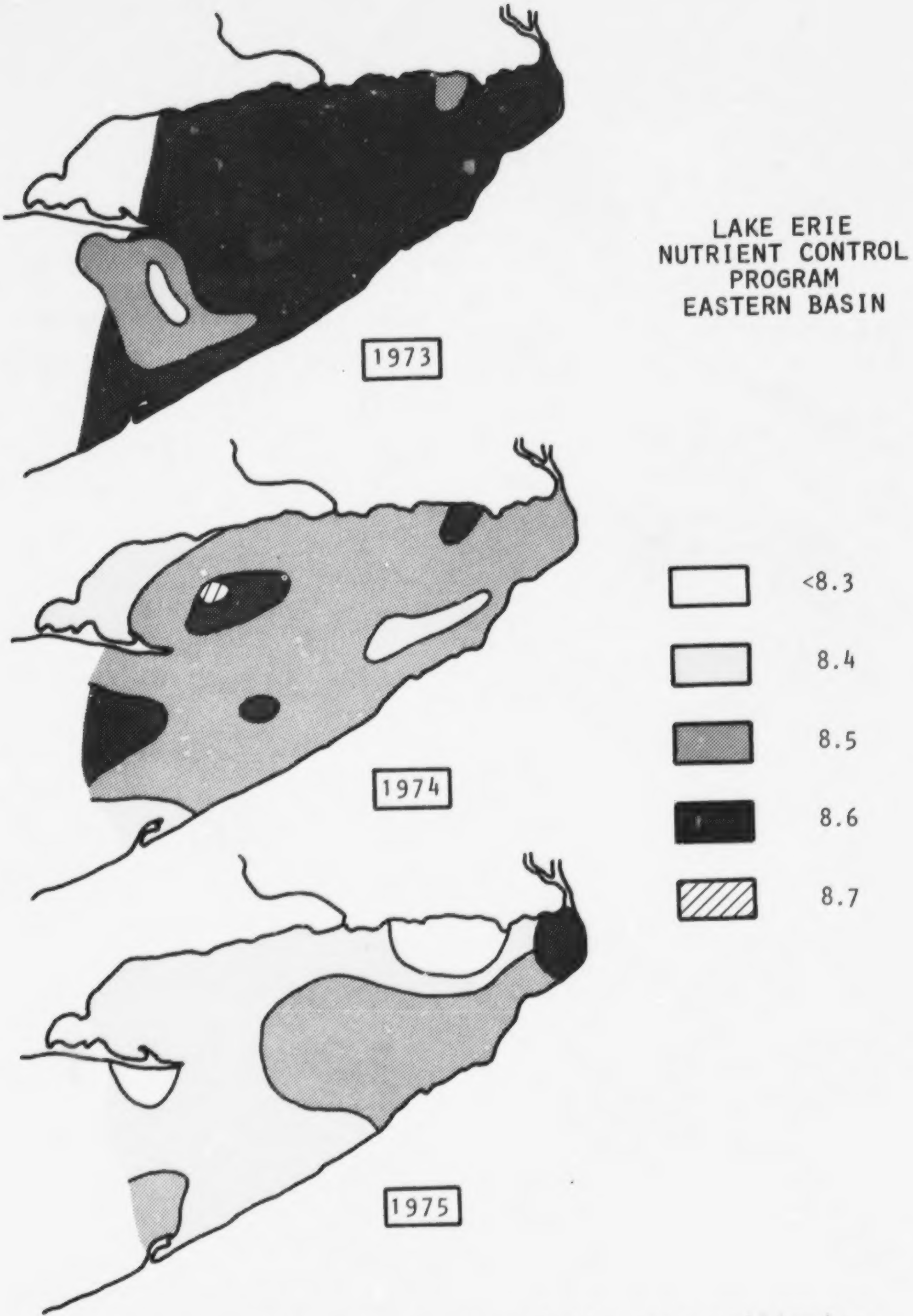

LAKE ERIE
NUTRIENT CONTROL
PROGRAM
EASTERN BASIN
1973
1974
1975
<8.3
8.4
8.5
8.6
8.7

Figure 8. Lake Erie Eastern Basin mean epilimnion pH (standard units) 1973-1975.

compared over the three years for each of the stations using discriminant analysis to detect changes in that particular area of the lake and furthermore identify these changes. The results of the analysis (Table 5) indicated that eight of the 26 stations were significantly different from themselves every year of the three. An additional eight stations were significantly different from themselves when 1974 water quality was compared with either 1973 or 1975. The water quality of these eight stations was not different, however, when 1973 and 1975 were compared. As illustrated by the diagrams in Figures 2-8 and the data in Table 5, the major parameters contributing to this variation between the three years were the nitrogen compounds of ammonia and nitrate and to a lesser extent total and dissolved phosphorus, dissolved oxygen and the physical parameters of Secchi disc and temperature. Therefore, considering all the facts that have been presented so far, it would appear that variation in the Eastern Basin of Lake Erie over the three years of 1973, 1974 and 1975 is primarily accounted for by variation in nitrogen.

Discriminant analysis was used on the physio-chemical variables measured at each station over the three years to differentiate specific water masses of the Eastern Basin based on variability of the factors measured. The maps in Figure 9 depict how the stations grouped together as distinct water masses for each of the three years. Since the discriminant analysis technique identified the significant variables that caused the separation of stations, it was possible to characterize the different water masses for each year observed in Figure 9.

In 1973 there were four discrete masses of water. The first represented by the eastern and southern shore stations (1, 2, 3, 4, 8, 62, 64) showed lower Secchi disc readings than any of the other areas. The northern shore stations (11, 12, 13, 14) displayed higher values of total nitrogen than the other groups. The mid-lake stations (5, 6, 7, 9, 10, 16) exhibited very high Secchi disc readings and higher dissolved oxygen measurements. The westernmost group of stations showed lower pH values than the other water masses.

The Basin was characterized by six discrete water masses in 1974. The eastern stations (1, 2, 3, 4, 5, 62) were described by high dissolved phosphorus values. The north shore stations (11, 12, 13, 80) were characterized by lower values of ammonia than other areas. The mid-lake stations (6, 9, 10, 14) showed relatively low measurements of total nitrogen and higher values of pH. The southern shore stations (7, 8, 15, 16, 22, 63, 64) displayed higher total nitrogen and lower ammonia values than the other groups of stations. The western group of stations (17, 18, 19, 20) also characterized by lower total nitrogen values and very low total phosphorus measurements defined the fifth area. The last water mass, Station 21, exhibited very low dissolved phosphorus and high pH compared to other areas of the Basin.

Table 5. RESULTS OF A DISCRIMINANT ANALYSIS FOR WATER QUALITY OF EACH EASTERN BASIN SAMPLING STATION COMPARED TO ITSELF OVER THE PERIOD 1973-1975

Also included are the factors that contributed most (by percent) to variation in each station over the three years

Station Number	1973	1974	1975	(%) Factors contributing to variation	
1	1974	■	1974	(75%) DP + TP	(25%) TN
2	1974	1973	□	(79%) COND + NH	(21%) SD
3	■	■	■	(67%) TN	(33%) SD
4	■	■	■	(87%) NH	(13%) SD
5	■	■	■	(96%) SD + NH	(04%) NO + SD
6	1974	■	1974	(95%) NH	(05%) SD
7	■	■	■	(90%) DO	(10%) NO
8	1974	■	1974	(99%) NH	(01%) TN
9	■	■	■	(98%) NH	(02%) DP
10	1974	■	1974	(99%) TP	(01%) PH
11	1975	1975	■	(89%) NH	(11%) DO
12	1975	1975	■	(98%) DO	(02%) NH
13	1974	■	1974	(88%) NH	(12%) PH
14	1975	1975	■	(83%) TEMP + SD	(17%) SD + DO
15	1974	■	1974	(86%) NH + NO	(14%) TN
16	□	1975	1974	(84%) NO	(16%) SD
17	1974	■	1974	(96%) CHL + NO	(04%) DO
18	□	1975	1974	(68%) TN + NH	(32%) NO
19	1974	■	1974	(75%) TEMP + PH	(25%) TEMP
20	■	■	■	(68%) DP	(32%) NO
21	□	□	□	(59%) NH	(41%) COND + DP
22	□	1975	1974	(85%) DO	(15%) DP
62	■	■	■	(99%) TN	(01%) SD
63	□	1975	1974	(85%) TEMP + DO	(15%) COND
64	■	■	■	(84%) SD	(16%) DO
80	□	□	□	(100%) COND + NH + DO	

□ No difference

■ Different from both years

□ Different only from indicated year

See Table 2 for list of abbreviations

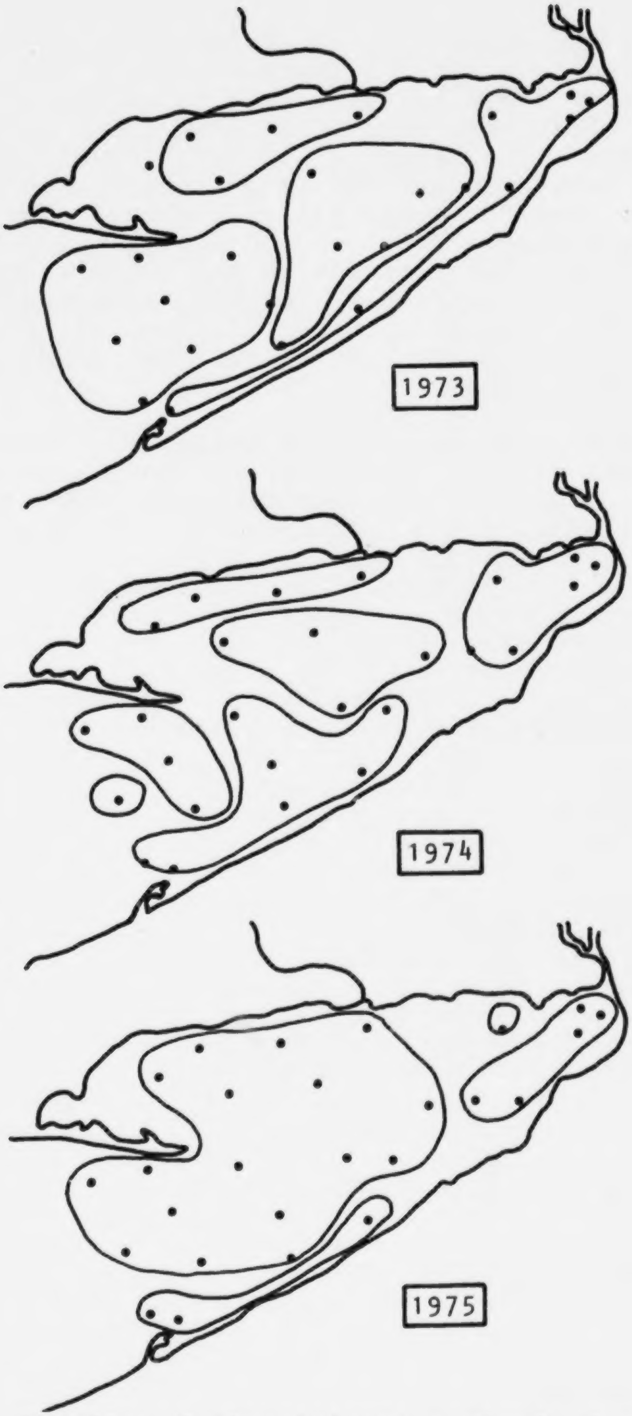


Figure 9. Results of discriminant analysis for epilimnion physio-chemical variables measured in the Eastern Basin 1973-1975. Station groupings represent areas of similar water quality.

In 1975 the sampling cruises identified four discrete groupings of stations for the Eastern Basin. The first represented by Station 1 was characterized by extremely low mean pH values of 7.9 which were much lower than found at any other collection sites. The second grouping of stations (2, 3, 4, 5, 62) displayed lower conductivity measurements and slightly higher nitrate values than the other discrete areas. The mid-lake and northern shore stations (6, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 63, 80) represented the third water mass which was characterized by extremely low nitrate values throughout the entire area. The last grouping of stations (8, 22, 64) was characterized by extremely high nitrate measurements compared to the previous water mass.

After analyzing each of the three years separately via discriminant analysis, it was apparent that there were some patterns that consistently reappeared each year. Therefore, the epilimnetic data for all 26 stations for the three years combined were analyzed with the discriminant procedure to obtain a picture of the Basin for the full duration of the study. The discrete water masses illustrated in Figure 10 are the result of this analysis. For the three years combined, the variables were able to discriminate five areas of the Basin that were different from one another. The first water mass was represented by the stations at the eastern end of the Basin and along the southern shore (1, 2, 3, 4, 5, 7, 8, 62). This area of the lake was discrete due to the combined effects of generally higher pH and higher measurements of total phosphorus. As indicated previously, Station 1 did show low mean pH values for 1975. These values suggested the results of an isolated event and the ultimate discriminating power of pH was not enough to separate this station from the other stations of this particular group. The second area of the Basin included several of the mid-lake stations and the north shore stations (6, 9, 10, 11, 12, 13, 14, 80). This group was characterized by lower nitrate values than the other water masses in the Basin. Station 11 had characteristics that were similar to both the water masses just described. Therefore, this station was located in the second group primarily because of geographical location. The third discrete water mass included the remaining mid-lake stations (15, 16, 63) and most of the western stations of the Basin (17, 18, 19, 20). This water mass was characterized by lower values of both total phosphorus and nitrate compared to the other station groupings. Station 21 tended to isolate from the other stations similar to what was observed from the 1974 data. This area of the Basin was discrete from all others because of the high measurements for total phosphorus observed. This station definitely showed effects of Central Basin water entering the Eastern Basin. The last area of the Basin which also showed effects of the Central Basin as well as effects believed to be from effluents of Erie, Pa. was the grouping of Stations 22 and 64. This mass of water was characterized by lower Secchi disc readings and higher values of

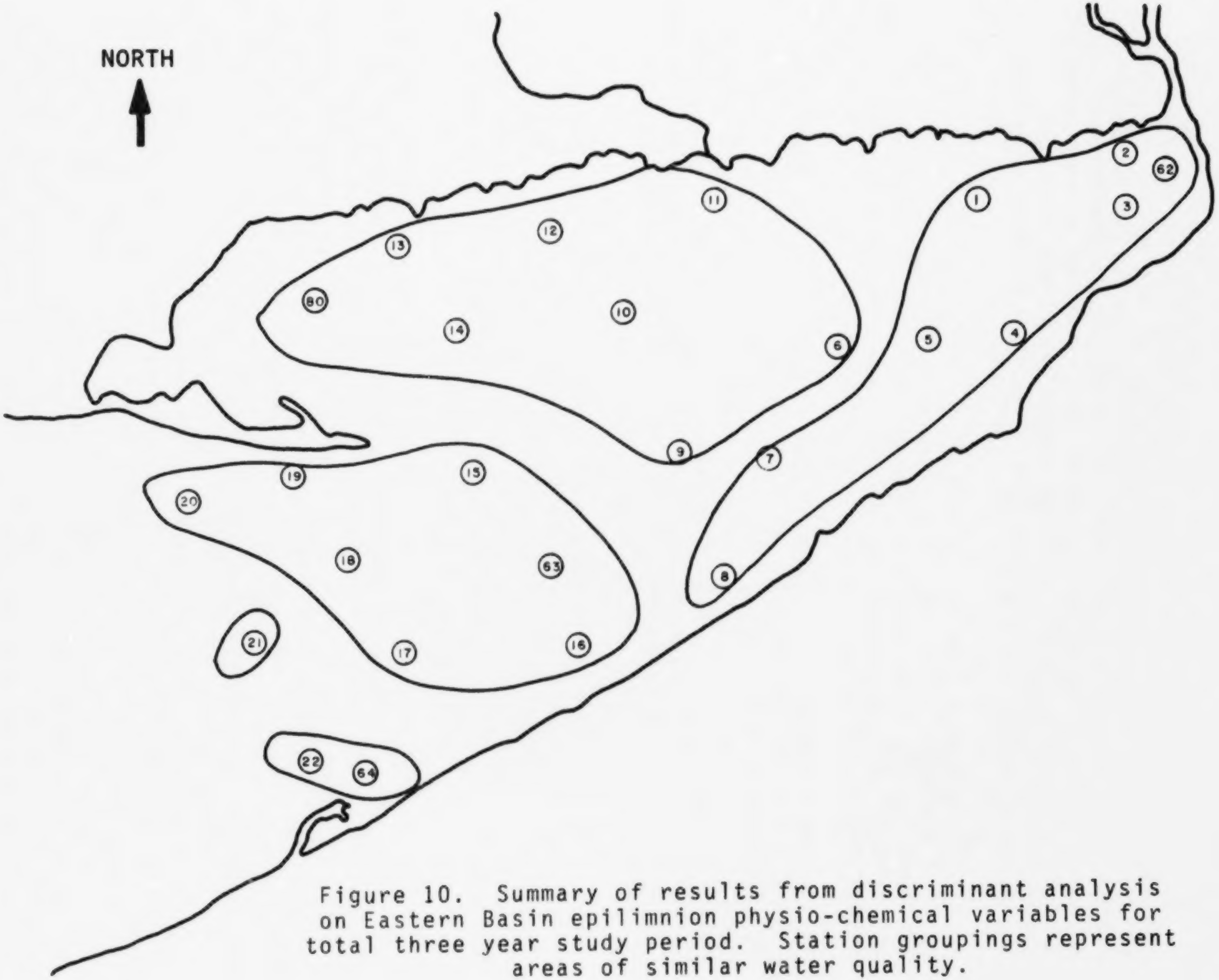

NORTH
2
62
3
1
4
5
11
12
13
80
14
10
6
9
7
8
19
15
20
18
63
21
17
16
22
64

Figure 10. Summary of results from discriminant analysis on Eastern Basin epilimnion physio-chemical variables for total three year study period. Station groupings represent areas of similar water quality.

nitrate than the other water masses of the Eastern Basin described above.

Due to the presence of a thermocline, which was characteristic of the deeper stations for much of the warmer seasons, several of the parameters measured showed trends in the hypolimnetic waters independent of the epilimnion. These waters were represented by the mid-hypolimnetic sample taken at each station of every cruise. During unstratified conditions, the mid-hypolimnetic sample was taken equally spaced between a bottom sample and a sample 5 m below the surface.

Hypolimnetic dissolved phosphorus (Figure 11) showed a gradual decrease over the three year period except for a slight increase in the eastern end of the Basin in 1974. For every year other than 1974 the deeper-water stations displayed consistently higher measurements of dissolved phosphorus.

The trend of total phosphorus (Figure 12) for the hypolimnetic waters was similar in some respects to the dissolved phosphorus concentrations. In general there was a consistent decline in total phosphorus over the entire Basin with the high values concentrating in the deeper waters, similar to dissolved phosphorus. Data from 1975 showed that the deep mid-lake stations appeared to be concentrating both the dissolved and total phosphorus (Figures 11 and 12) of the Basin.

The nitrate measurements (Figure 13) of the hypolimnetic waters again appeared to follow the nitrogen pattern for the epilimnetic waters. There was a definite increase observed in nitrate in 1974 compared to either 1973 or 1975. Furthermore, the higher concentrations of nitrate were found in the deeper areas of the Basin similar to phosphorus.

Discriminant analysis was done on all the offshore stations (>25 m) to differentiate discrete masses of hypolimnetic waters. There was little difference between the results of the three years analyzed separately. Therefore, the analysis was performed on the 13 offshore stations for all three years combined. The results of this analysis (Figure 14) showed that the hypolimnetic waters could be discriminated into four discrete water masses. Furthermore, it appeared as though this separation of stations had some relation to water depth. The first group of stations (6, 7, 10, 16, 17, 18, 19) appeared to separate from the other water masses primarily due to higher water temperatures caused by shallower depths. The second group (9, 14, 15, 63) was a discrete water mass and was characterized by the combined effects of lower water temperature and higher values of total phosphorus. The remaining two areas, Stations 20 and 21, respectively, represented different water from the other two areas based primarily on higher water temperatures intruding from the Central Basin and differences in total and dissolved phosphorus. These areas (Stations 20

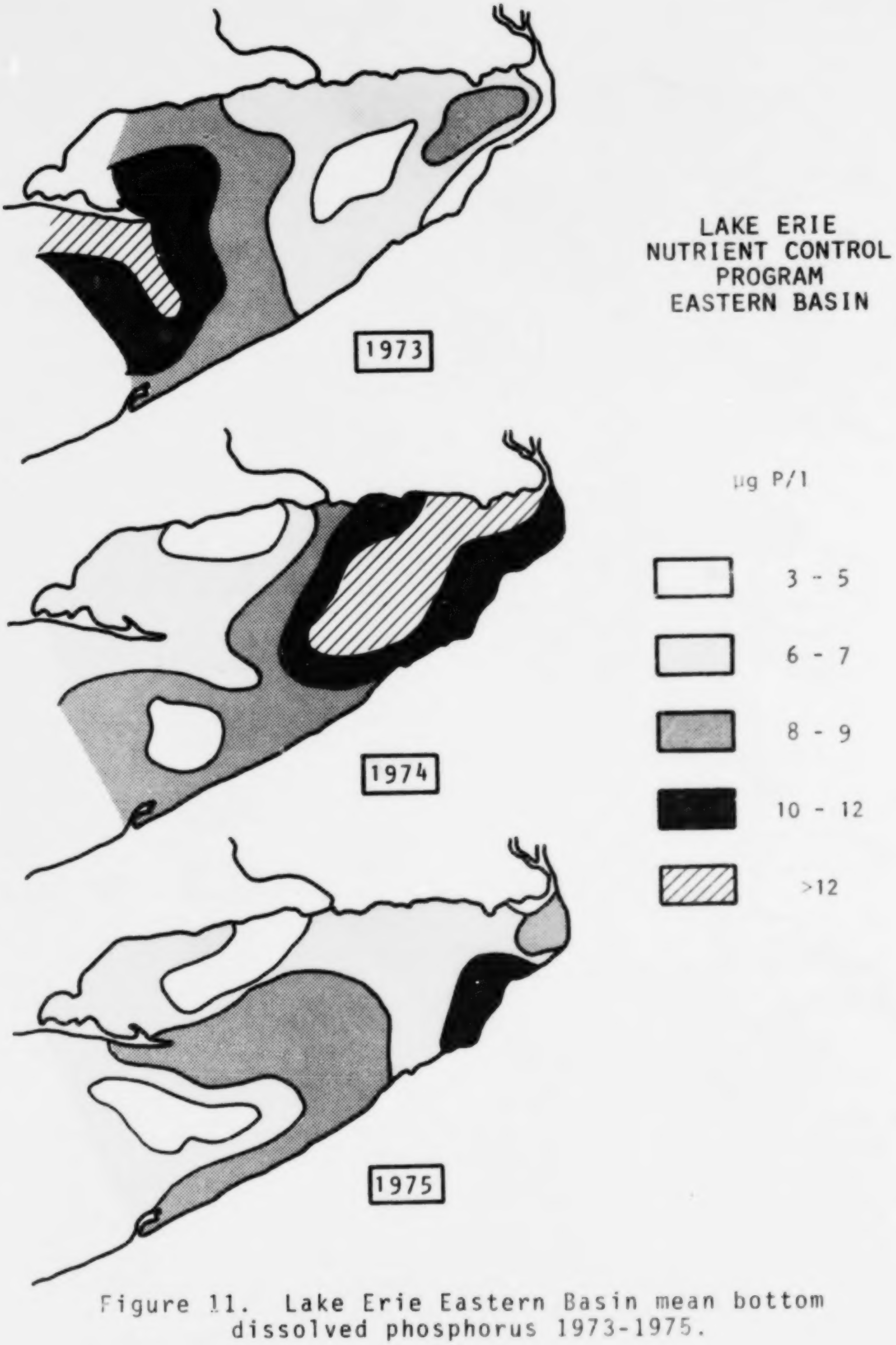

LAKE ERIE
NUTRIENT CONTROL
PROGRAM
EASTERN BASIN
1973
1974
1975
µg P/l
3 - 5
6 - 7
8 - 9
10 - 12
>12

Figure 11. Lake Erie Eastern Basin mean bottom dissolved phosphorus 1973-1975.

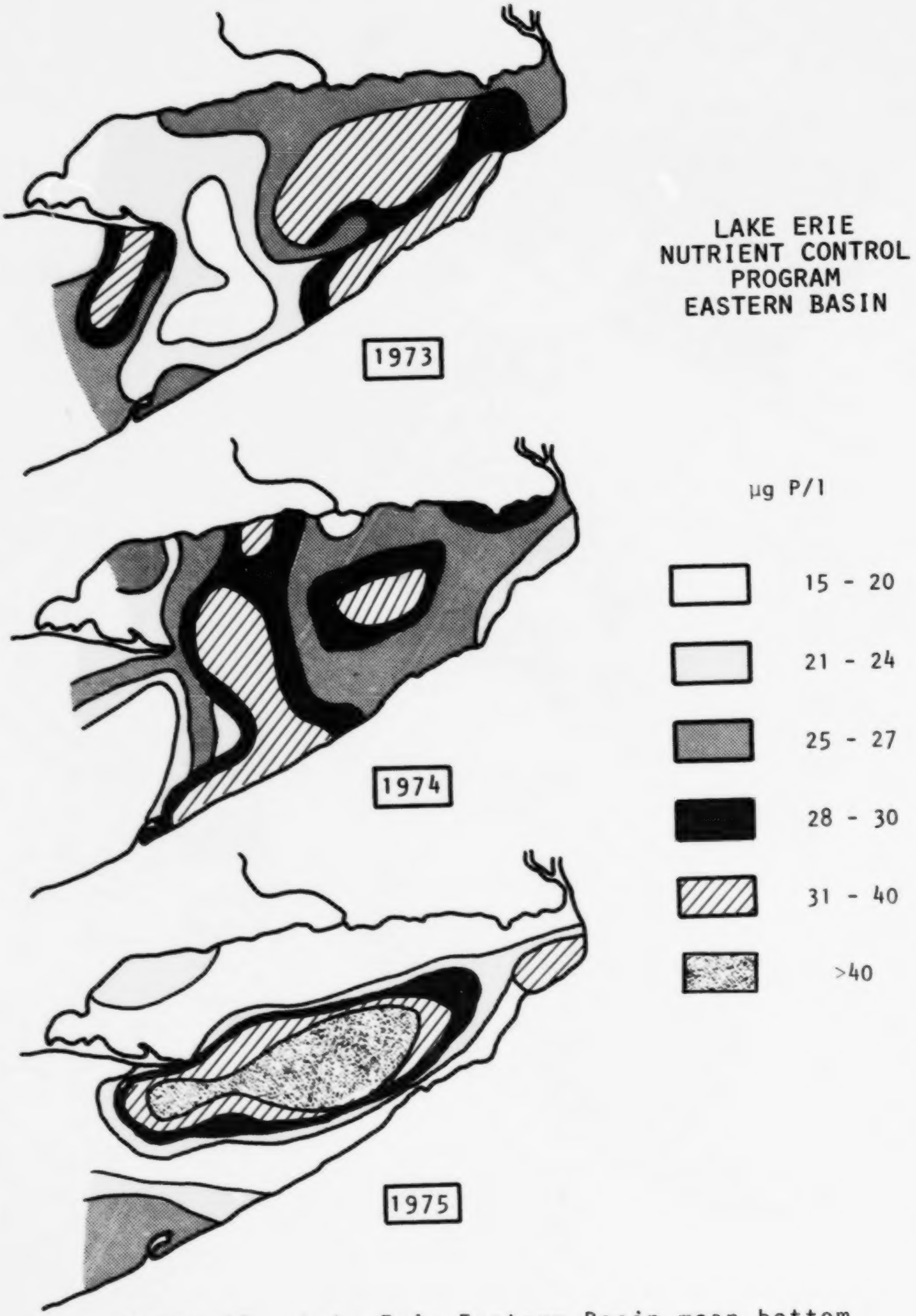

LAKE ERIE
NUTRIENT CONTROL
PROGRAM
EASTERN BASIN
1973
1974
1975
µg P/l
15 - 20
21 - 24
25 - 27
28 - 30
31 - 40
>40

Figure 12. Lake Erie Eastern Basin mean bottom total phosphorus 1973-1975.

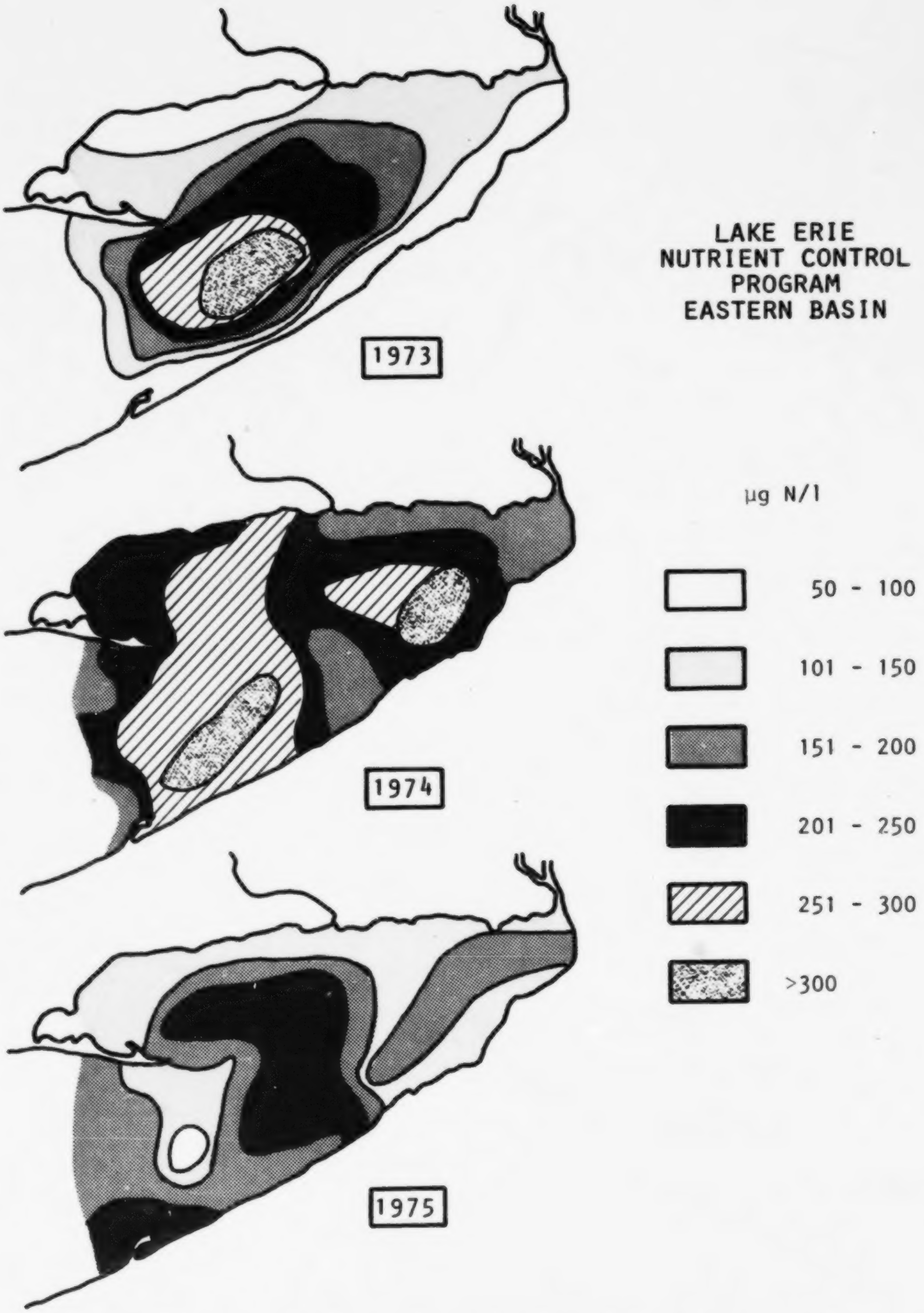

LAKE ERIE
NUTRIENT CONTROL
PROGRAM
EASTERN BASIN
1973
1974
1975
µg N/l
50 - 100
101 - 150
151 - 200
201 - 250
251 - 300
>300

Figure 13. Lake Erie Eastern Basin mean bottom nitrate-nitrite 1973-1975.

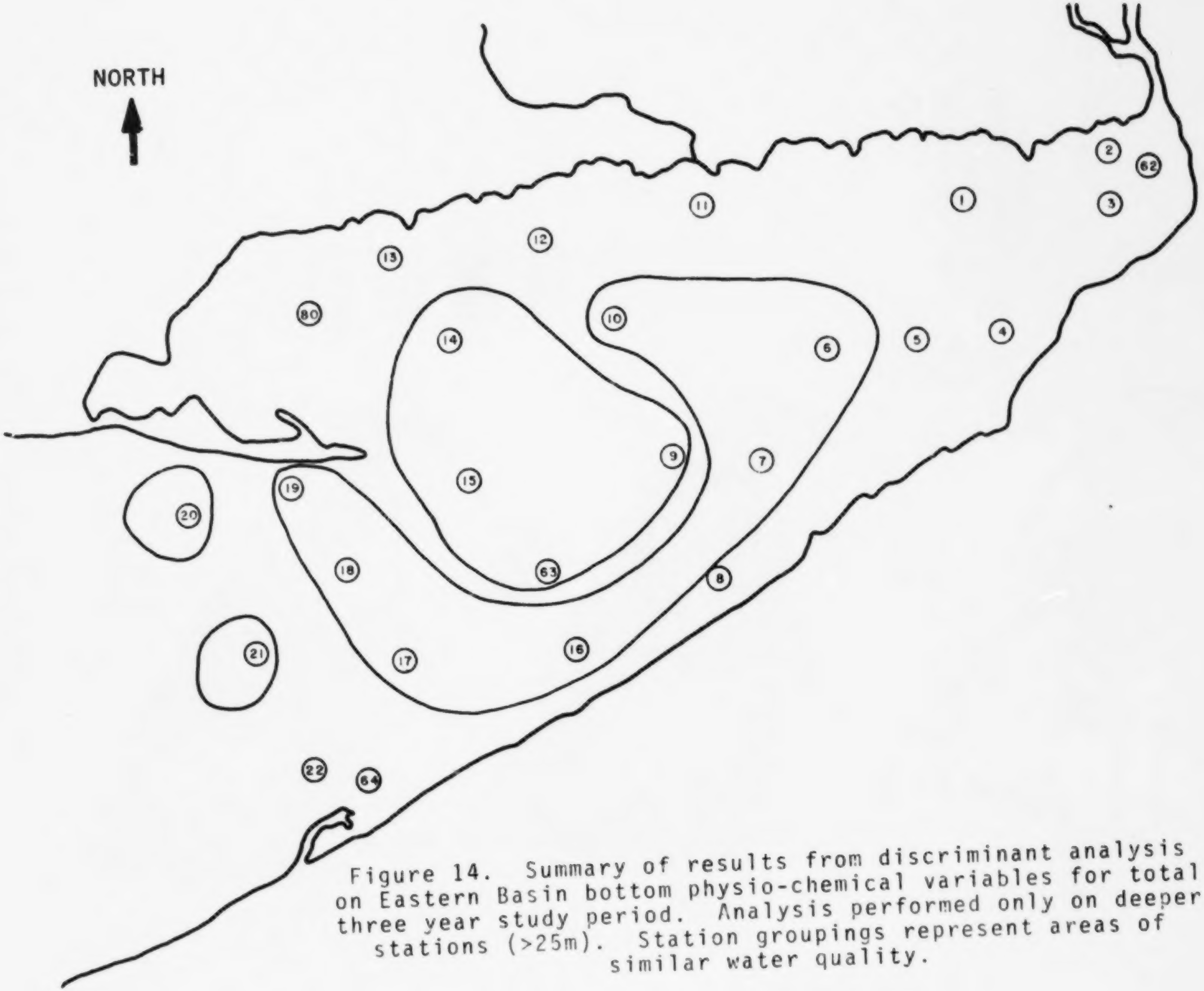

NORTH
2
62
3
1
11
12
13
80
10
6
5
4
14
9
7
15
19
20
18
63
8
16
17
21
22
64

Figure 14. Summary of results from discriminant analysis on Eastern Basin bottom physio-chemical variables for total three year study period. Analysis performed only on deeper stations (>25m). Station groupings represent areas of similar water quality.

and 21) were also discrete from one another due to Station 20 being characterized by lower values of total and dissolved phosphorus and alternatively Station 21 displaying the opposite trend of high dissolved and total phosphorus.

The Eastern Basin of Lake Erie showed a very unstable thermal structure over the period of this three year study. The classical scheme of thermocline formation was apparent in the lake, usually in early June (Figure 15a and 16a). This thermocline and its associated metalimnion showed a downward movement as summer progressed, again in a classical fashion (Figure 15b and 16b). The metalimnion, however, was not always complete over the entire Basin during many of the summer cruises of the three years (Figures 15c, 15d, 16c and 16d). With the break-up of this metalimnion, usually resulting from heavy surface storms and internal water movements, major upwelling occurred in the deeper parts of the Basin as seen in Figures 15c and 16d. This upwelling phenomena caused a great deal of mixing between cold hypolimnetic water and the warmer epilimentic waters, resulting in both a cooling of the epilimnion and a warming of the hypolimnion. Over the three year duration, the stratification usually eroded to a unithermal condition by mid-October. After the ice cover was gone (i.e. April) the unithermal condition was again observed during cruises in this period.

The data collected on dissolved oxygen suggested that levels fluctuated in the Eastern Basin on a seasonal basis. During early spring, surface waters were saturated with oxygen. Bottom waters during this period were also near saturation. As the summer season progressed and stratification became more pronounced, the hypolimnetic waters began to show a depletion of oxygen. For example, during the last cruise of 1975 that exhibited conditons of stratification, the hypolimnetic waters were at levels of 50 to 65% saturation and the volume of the hypolimnion had steadily decreased.

From temperature data collected during 1973, 1974 and 1975 field years, the hypolimnion boundaries were plotted and then measured with a planimeter. Plots of hypolimnetic thickness were used to calculate the hypolimnetic volume (Figure 17 - Cruise 3 of 1975). Also, incorporating oxygen data using the Winkler Standardized oxygen probe (American Public Health Association, 1971), hypolimnetic oxygen depletion was calculated.

During the period of thermal stratification in all three years of the study the hypolimnion did exhibit oxygen depletion. In order to determine the rate and level of this oxygen depletion, a Mesolimnion Erosion Model (Burns and Ross, 1972) was constructed. This model assumed:

1) Volumetric changes of the hypolimnion caused by the loss or gain of water,

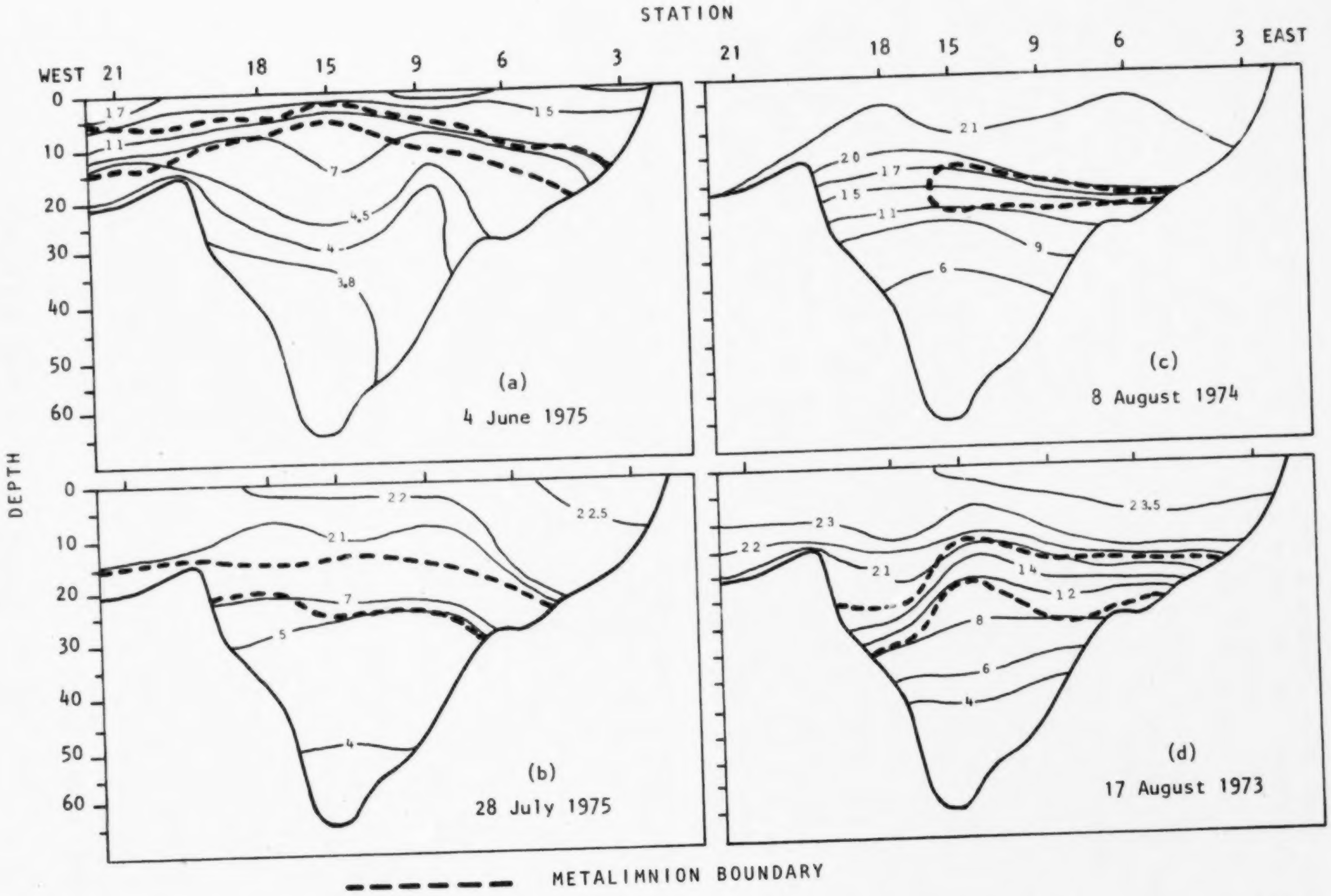


Figure 15. Variations in thermal dynamics of Lake Erie Eastern Basin as represented by temperature-depth profiles on a transect of the longitudinal (east-west) axis of the Basin (Stations 3, 6, 9, 15, 18 and 21).

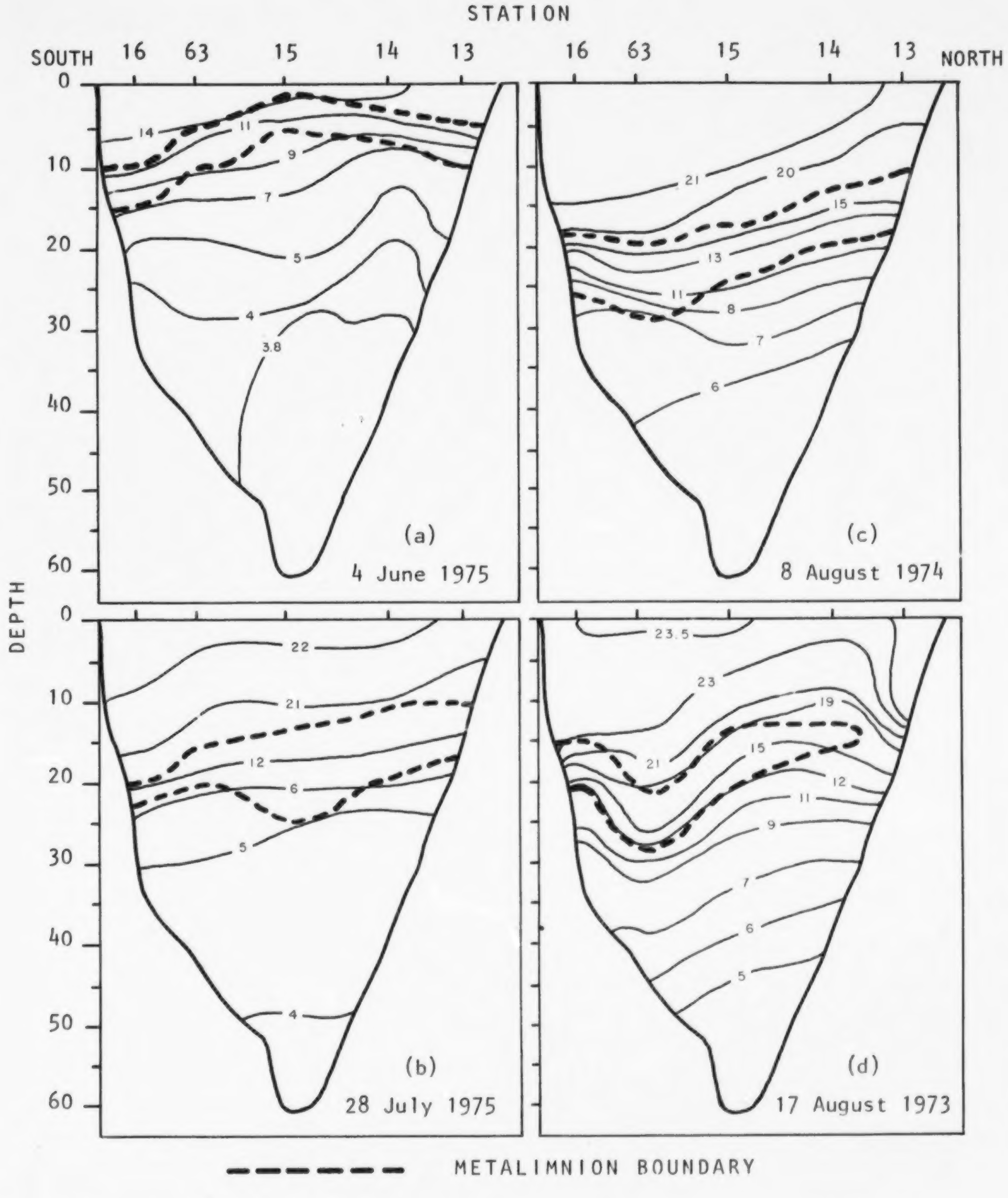


Figure 16. Variations in thermal dynamics of Lake Erie Eastern Basin as represented by temperature-depth profiles on a transect of the cross-lake (south-north) axis of the Basin (Stations 16, 63, 15, 14 and 13).

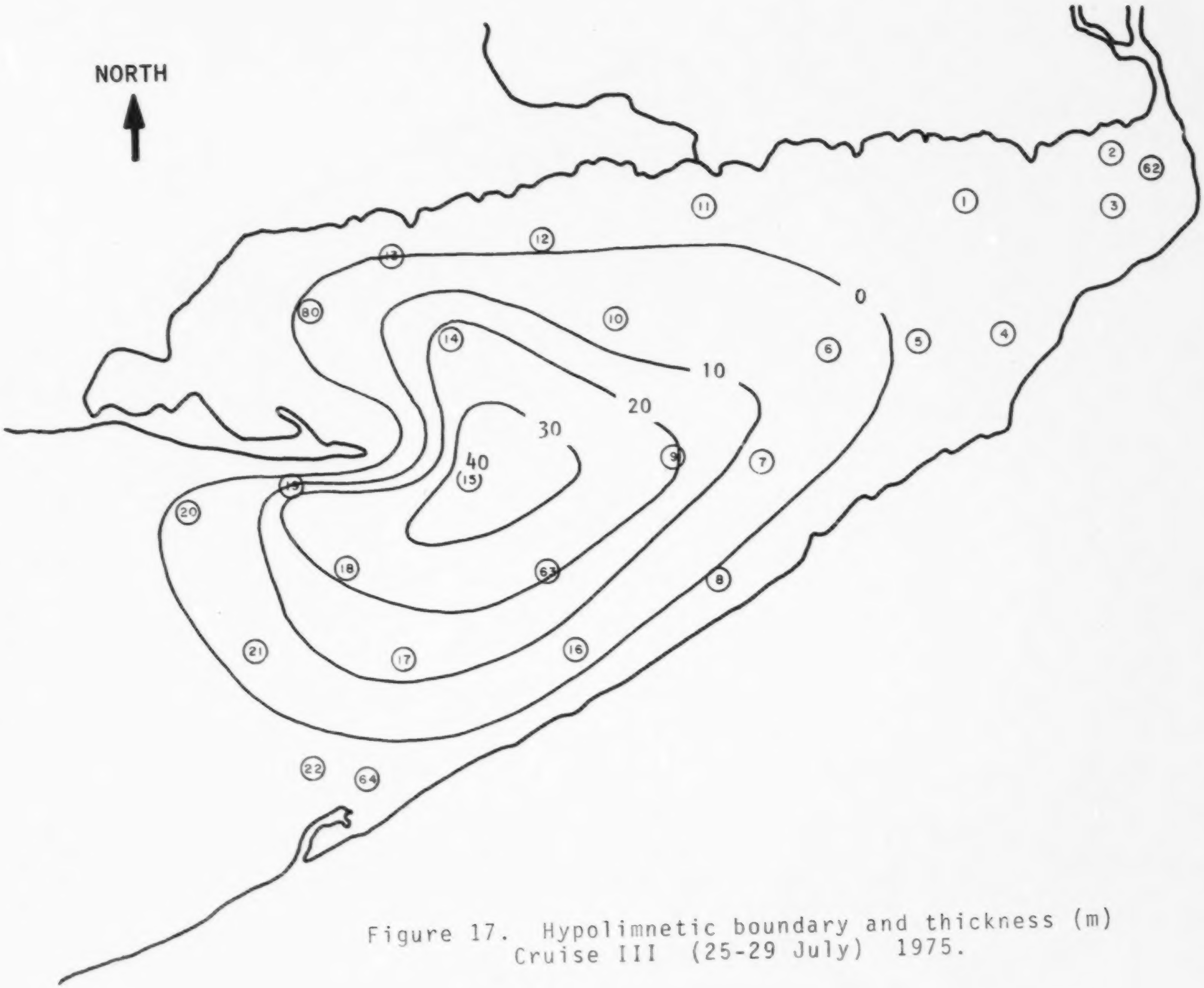

NORTH
0
10
20
30
40
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
62
63
64
80

Figure 17. Hypolimnetic boundary and thickness (m) Cruise III (25-29 July) 1975.

including dissolved oxygen to or from the overlying metalimnion.

2) Exchange of water between the metalimnion and hypolimnion, including dissolved oxygen, without volumetric changes in either layer.

The results of this model construction for each of the three years is presented in Tables 6, 7 and 8, respectively. The summary of the Eastern Basin oxygen demand for the three years of this study (Table 9) showed that the oxygen demand for 1973 was 0.012 $gO_2/m^3/day$ (4 July - 15 September). In 1974 the oxygen demand for approximately the same time period (8 July - 9 October) was 0.011. In 1975 the oxygen demand for the Eastern Basin was calculated to be 0.040 $gO_2/m^3/day$ for the dates of 2 June - 18 September. This is in agreement with the oxygen demand for 1974 (0.040) calculated between the dates of 4 June - 9 October. Since the oxygen demand was equal between 1973 and 1974 for similar time periods and the oxygen demand was also equal between 1974 and 1975 for similar time periods, it was assumed that there was essentially no change in oxygen levels of demand over the three years.

In general the demand per unit area was very small for the hypolimnion and it would appear that the hypolimnetic oxygen demand has stabilized. Furthermore, the constant erosion of the metalimnion during peak stratification periods (Figure 15c and 16d) was an added source of reoxygenation for the hypolimnion waters, reducing chances of oxygen depletion.

Although functional or cause and effect relationships cannot be determined from correlation analayses, the results do indicate associated variables and how one parameter varies in relationship to another parameter (Sokal and Rohlf, 1969). There were a significant number of correlations, as expected from a correlation matrix constructed of 11 variables with more than 300 observations. Table 10 illustrates the relationships between variables that were highly significant ($P \leqslant 0.001$). As expected, the nitrogen compounds were all correlated with one another as were total and dissolved phosphorus. Dissolved oxygen was negatively correlated with temperature, Secchi disc, conductivity and pH. The temperature-dissolved oxygen correlation would be expected since increases in temperature classically reflect decreases in oxygen. Secchi disc was strongly correlated with temperature implying that the less turbid waters permit deeper penetration of light and increased heating. Consequently, Secchi disc was negatively correlated with dissolved oxygen because of the temperature increases with increased water clarity. Conductivity was negatively correlated with dissolved oxygen because of the positive relationship between conductivity and normal

Table 6. SUMMARY OF 1973 HYPOLIMNETIC SURVEYS OF THE EASTERN BASIN OF LAKE ERIE

Cruise	Date	Area (km^2)	Volume (km^3)	Total Heat (kcal x 10^{12})	Total O_2 (kgO_2 x 10^6)
I	11-27 June	INCOMPLETE DATA			
II	4-10 July	3048.3	69.27	819.5	556.2
III	10-16 July	2865.8	55.65	631.1	417.4
IV	31 July - 6 Aug	2541.0	53.69	642.1	327.0
V	15-20 August	2581.0	48.99	553.1	306.2
VI	11-15 September	INSUFFICIENT TEMPERATURE DATA			
VII	1-5 October	2322.9	33.82	304.4	206.3
VIII	8-11 October	1615.4	21.11	145.2	118.6
IX	22-26 October	LAKE NON-STRATIFIED			
X	8-12 December	LAKE NON-STRATIFIED			

Cruise	Mean O_2 Conc. (mg/l)	Mean Temp. (°C)	Mean O_2 Grad. Across Mesolimn. (gO_2/m^4)	Mean Temp. Grad. Across Mesolimn. (°C/m)
I		INCOMPLETE DATA		
II	8.03	11.83	0.219	1.94
III	7.50	11.34	0.331	1.81
IV	6.09	11.96	0.698	1.96
V	6.25	11.29	0.522	2.24
VI		INSUFFICIENT TEMPERATURE DATA		
VII	6.10	9.00	0.779	2.07
VIII	5.62	6.88	0.861	2.22
IX		LAKE NON-STRATIFIED		
X		LAKE NON-STRATIFIED		

Table 7. SUMMARY OF 1974 HYPOLIMNETIC SURVEYS OF THE EASTERN BASIN OF LAKE ERIE

Cruise	Date	Area (km^2)	Volume (km^3)	Total Heat (kcal x 10^{12})	Total O_2 (kgO_2 x 10^6)
I		MECHANICAL FAILURE			
II		MECHANICAL FAILURE			
III		MECHANICAL FAILURE			
IV	21 May - 2 June	INSUFFICIENT TEMPERATURE DATA			
V	4-7 June	3956.1	107.80	960.5	1216.0
VI	18-22 June	2411.9	43.55	421.6	456.8
VII	8-11 July	2772.4	49.48	617.5	451.8
VIII	26-30 July	3666.8	59.67	818.1	449.3
IX	6-9 August	2572.1	47.92	642.1	356.5
X	12-16 August	2923.7	50.35	687.3	319.7
XI	6-9 September	2816.9	40.10	394.6	267.1
XII	16-21 September	1882.4	25.88	249.5	181.7
XIII	1-9 October	1108.1	13.52	131.4	92.2
XIV	23-27 October	INSUFFICIENT TEMPERATURE DATA			
XV	5-11 November	485.1	4.37	42.5	29.8
XVI	19 Nov - 5 Dec	LAKE NON-STRATIFIED			

Cruise	Mean O_2 Conc. (mg/l)	Mean Temp. (°C)	Mean O_2 Grad. Across Mesolimn. (gO_2/m^4)	Mean Temp. Grad. Across Mesolimn. (°C/m)
I		MECHANICAL FAILURE		
II		MECHANICAL FAILURE		
III		MECHANICAL FAILURE		
IV		INSUFFICIENT TEMPERATURE DATA		
V	11.28	8.91	0.180	0.80
VI	10.49	9.68	0.090	0.77
VII	9.13	12.48	0.440	1.26
VIII	7.53	13.71	0.610	1.54
IX	7.44	13.40	0.410	2.14
X	6.35	13.65	0.460	1.73
XI	6.66	9.84	0.350	1.68
XII	7.02	9.64	0.350	1.67
XIII	6.82	9.72	0.800	1.30
XIV		INSUFFICIENT TEMPERATURE DATA		
XV	5.88	8.85	2.880	2.40
XVI		LAKE NON-STRATIFIED		

Table 8. SUMMARY OF 1975 HYPOLIMNETIC SURVEYS OF THE EASTERN BASIN OF LAKE ERIE

Cruise	Date	Area (km^2)	Volume (km^3)	Total Heat (kcal x 10^{12})	Total O_2 (kgO_2 x 10^6)
I	9-12 April	LAKE NON-STRATIFIED			
II	2-5 June	3764.7	75.2	458.7	925.0
III	25-29 July	2932.6	39.4	295.5	350.7
IV	15-18 September	2443.1	34.0	316.2	275.4
V	7-9 December	LAKE NON-STRATIFIED			

Cruise	Mean O_2 Conc. (mg/l)	Mean Temp. (°C)	Mean O_2 Grad. Across Mesolimn. (gO_2/m^4)	Mean Temp. Grad. Across Mesolimn. (°C/m)
I		LAKE NON-STRATIFIED		
II	12.3	6.1	0.19	1.43
III	8.9	7.5	0.37	2.45
IV	8.1	9.3	0.26	2.70
V		LAKE NON-STRATIFIED		

Table 9. HYPOLIMNETIC OXYGEN DEMAND IN THE EASTERN BASIN OF LAKE ERIE 1973-1975

Year	Date	# Days	Demand/Unit Area ($gO_2/m^2/day$)	Demand/Unit Volume ($gO_2/m^3/day$)	Demand/Unit Area ($mmoleO_2/m^2/day$)
1973	4 July - 15 Sept	99	0.23	0.012	7.188
1974	4 June - 9 Oct*	127	0.95	0.040	29.688
	8 July - 9 Oct**	93	0.18	0.011	5.625
1975	2 June - 18 Sept	108	0.76	0.040	23.750

* The greater demand over this time period for both per unit area and per unit volume is believed to be a function of the much higher volume, area, total heat content and total oxygen in the hypolimnion during early spring cruises. See summary tables 7 and 8.

** Demand during this time period used for comparison with 1973 results.

Table 10. CORRELATIONS BETWEEN SIGNIFICANTLY RELATED VARIABLES IN THE EASTERN BASIN OF LAKE ERIE 1973-1975

$N = 324$ -and- R at $P < 0.001 = 0.1804$

	pH	Conductivity	Dissolved Oxygen	Secchi Disc	Temperature	Nitrate (NO_3)	NH_3	Dissolved Phosphorus
Conductivity	0.8712	-	-0.7665	-	-	0.2796	0.2302	-
Dissolved Oxygen	-0.8919	-	-	-0.2809	-0.4237	-	-	-
Temperature	0.4490	-	-	0.7549	-	-	-	-
Total Nitrogen	-	0.2574	-	-	-	0.3710	0.3214	-
Total Phosphorus	-	-	-	-	-	-	-	0.3274

biological activity. Increased biological activity (i.e. plankton blooms and decomposition) will result in net reduction of dissolved oxygen. One further connection in this relationship was that conductivity was positively correlated with the three nitrogen forms.

PHYTOPLANKTON

The detailed listings of phytoplankton species observed in the Eastern Basin of Lake Erie from 1973 to 1975 are contained in the Annual Reports (Great Lakes Laboratory, 1974; 1975; 1976).

There were 46, 44 and 62 species observed each year for 1973, 1974 and 1975, respectively. Nearly 50% of the species identified each year belonged to the Chlorophyta. Over the duration of the study, however, the Chlorophyta was not the dominant contributor to the group composition of biomass (Table 11). The major contributions to total biomass were the Chrysophyta in 1973 and 1975 and the Cryptophyta in 1974. The Chlorophyta, however, were consistently one of the major groups contributing to total biomass.

The algal biomass and its group composition for the three years of the study for the Eastern Basin are summarized in Table 11 as cruise averages. Considering the total mean biomass, it is quite evident that there is a definite decrease from 1973 to 1975. The Cyanophyta, which were consistently one of the larger contributors to total biomass in 1973 and 1974, displayed a sharp decline in 1975. The Chlorophyta and Chrysophyta each displayed relatively similar levels for the respective groups in 1973 and 1975 but exhibited decreases of up to 50% for their group composition to total biomass in 1974. On the other hand, the Cryptophyta group contribution in 1974 doubled compared to this group's contribution in both 1973 and 1975.

The horizontal distribution of phytoplankton biomass in the epilimnetic waters of the Eastern Basin during 1973, 1974 and 1975 are shown in Figure 18. The major areas of activity in 1973 appeared to be in the midbasin region of the lake, the southwestern end of the Basin (influences from the Central Basin) and the waters represented by the southeastern stations. The mean distribution of phytoplankton for 1974 again showed high activity at the eastern end of the Basin and a pulse in the western end. The midbasin activity shifted slightly and was now concentrating more on the northern side of the Basin. In general the mean biomass ranges were relatively consistent between 1973 and 1974. The picture in 1975, however, was very different. Again there was a pulse of activity at the western end of the Basin indicative of Central Basin influences. This pulse, however, was approximately half of the concentration of phytoplankton observed in 1973. The midlake and eastern stations showed a sharp decline in mean biomass in 1975. There was a pulse noted in Long Point Bay which was not much different from

Table 11. MEAN VALUES OF PHYTOPLANKTON BIOMASS AND ITS % COMPOSITION FOR ALL SAMPLING CRUISES IN LAKE ERIE EASTERN BASIN 1973-1975.

	1973					1974						1975				
Cruise #	II	IV	VII	VIII	X	IV	VI	VIII	XI	XIV	XVI	I	II	III	IV	V
Date	Jul 4-10	Jul 31-Aug 6	Sep 11-15	Oct 1-5	Dec 8-12	Jun 4-7	Jun 18-22	Jul 26-30	Sep 6-9	Oct 23-27	Nov 19 -Dec 5	Apr 9-12	Jun 2-5	Jul 25-29	Sep 15-18	Dec 7-21
Phytoplankton Biomass (10^3 mg/m^3)	0.66	1.59	1.62	1.54	1.86	1.50	0.43	0.81	3.72	0.44	1.04	0.75	0.32	0.47	0.69	1.52
						% Composition										
Cyanophyta	2.06	2.19	22.50	21.57	8.85	0.21	10.07	-	58.92	5.28	0.71	-	1.63	0.04	1.25	-
mean annual %					11.43						12.52					0.97
Chlorophyta	39.45	37.36	13.12	10.97	2.59	0.21	2.12	29.96	7.25	17.48	9.41	0.01	-	63.52	66.16	2.15
mean annual %					20.70						11.07					28.96
Chrysophyta	0.15	6.35	26.14	15.31	82.69	5.92	-	6.88	0.24	1.86	77.38	87.09	5.32	4.75	12.16	94.09
mean annual %					26.13						13.67					32.19
Cryptophyta	42.53	12.91	22.40	31.39	5.70	72.12	80.13	62.92	5.17	72.82	7.97	6.24	58.80	30.56	18.49	3.43
mean annual %					22.99						50.18					23.50
Flagellates	0.58	0.51	1.14	1.53	-	2.05	4.90	0.24	0.60	3.01	0.29	1.41	21.58	1.12	1.78	0.30
mean annual %					0.94						1.85					5.24
Pyrrhophyta	14.30	40.69	14.71	19.23	0.14	19.69	2.77	-	26.82	1.40	4.22	5.15	13.13	-	-	-
mean annual %					17.81						10.98					9.14

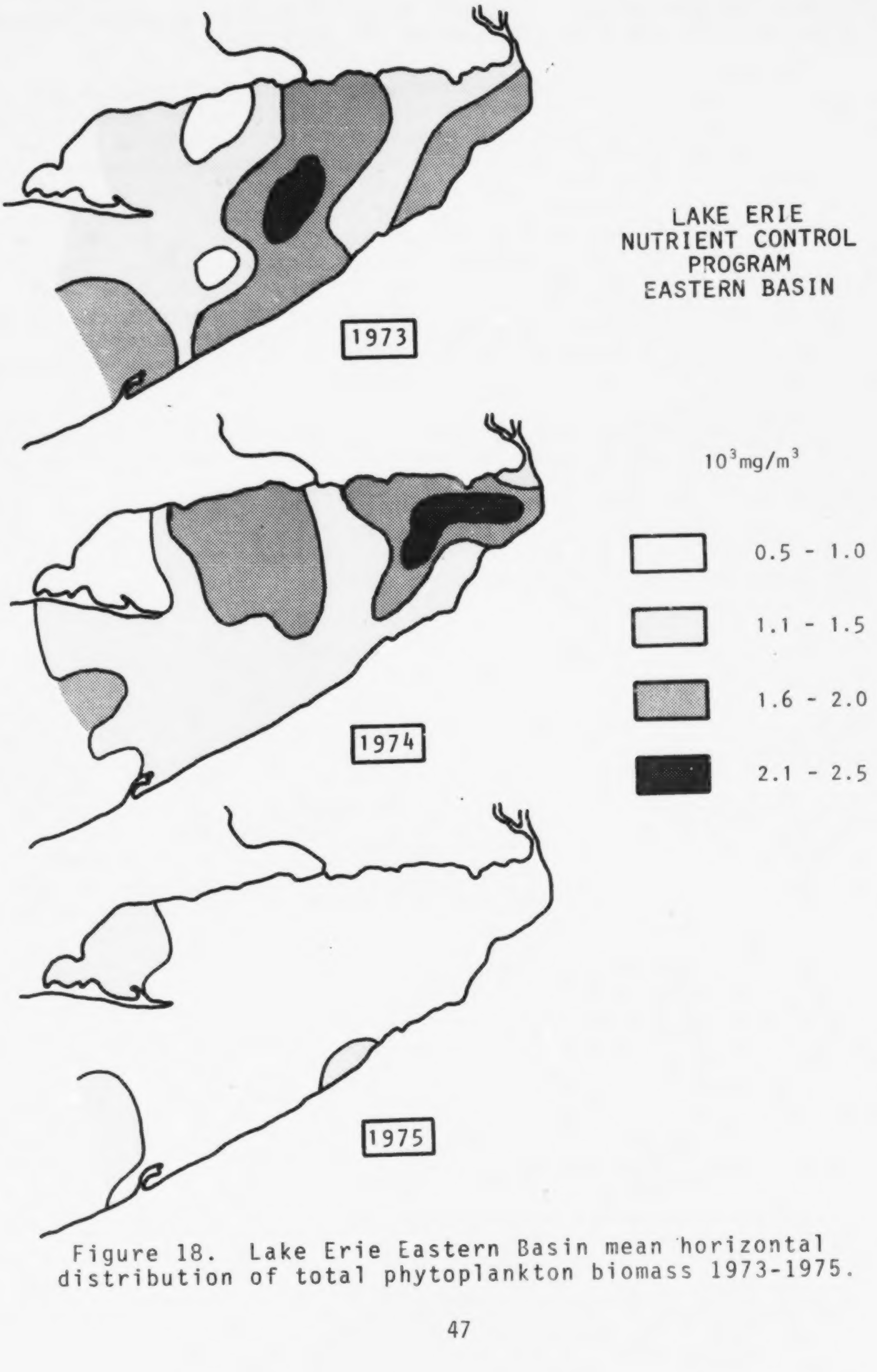

LAKE ERIE
NUTRIENT CONTROL
PROGRAM
EASTERN BASIN
1973
10³mg/m³
0.5 - 1.0
1.1 - 1.5
1.6 - 2.0
2.1 - 2.5
1974
1975

Figure 18. Lake Erie Eastern Basin mean horizontal distribution of total phytoplankton biomass 1973-1975.

the previous two years. Another area of higher biomass concentration in 1975 was off the shores of Barcelona.

The seasonal biomass fluctuation for the three years (Figure 19) generally indicated that a small pulse of activity was reached in the spring and a maximum peak attained in the fall (September and October) with minimum biomass observed during the summer. It must be noted that in both 1973 and 1975 there was a very large increase in biomass in December. This increase may have been a false indicator though, since a much smaller number of stations was sampled during these cruises. The seasonal variation of chlorophyll-a, primary production and biomass by group composition for the epilimnion are also shown in Figure 19. Chlorophyll-a tended to follow the seasonal patterns for total biomass but primary productivity showed some discrepancies.

One biomass maximum was observed in 1973 in mid-September when the phytoplankton concentration reached 1.62 g/m^3. This peak was composed primarily of Chrysophyta, Cyanophyta and Cryptophyta. The chlorophyll-a showed a lag period before reaching its peak (6.5 mg/m^3) in early October. The Cryptophyta dominated during this period. As the diatoms (Chrysophyta) became the dominant group, late in the fall, the chlorophyll-a showed a definite decline.

Two biomass maxima were observed in 1974, probably due to earlier cruises scheduled during this field year. A smaller maximum (1.55 g/m^3) was displayed in the spring (late May - early June) with the Cryptophyta composing the majority of the biomass. The Cryptophyta continued to dominate through the summer until early September. Chlorophyll-a also showed a peak (7.1 mg/m^3) during the spring maxima and then declined through the summer. Primary productivity, however, did not show its first peak of 1974 until late July (15.2 mg C/m^3/hr), well after the peak spring biomass. During this peak in productivity, the Cryptophyta were still the dominant group but the Chlorophyta had also increased.

The fall maximum for phytoplankton biomass (3.72 g/m^3) was observed in mid-September and the major groups contributing to this were Cyanophyta and Pyrrhophyta. The peaks of both chlorophyll-a (7.1 mg/m^3) and primary productivity (16.2 mg C/m^3/hr) were similar, but both lagged behind the peak biomass estimates. Again, similar to the early peak in chlorophyll and productivity, as well as the peak in 1973, for both time periods the Cryptophyta were the dominant group and as the Chrysophyta increased, both productivity and chlorophyll declined.

Two peaks of phytoplankton biomass were observed in 1975 but these were much smaller in magnitude than the peaks observed in 1973 or 1974. The first peak occurred in the early spring

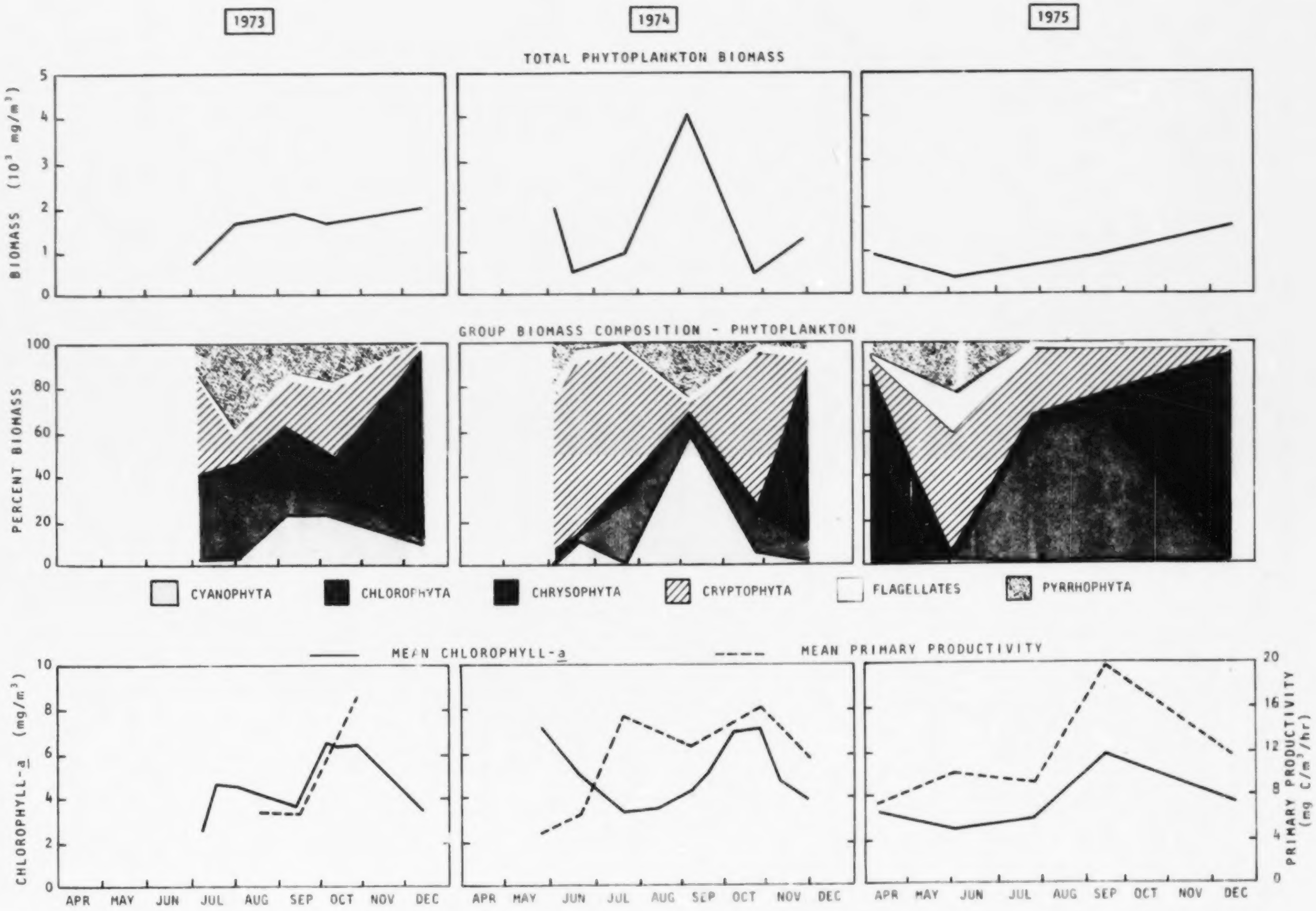


Figure 19. Seasonal fluctuations of phytoplankton biomass, its group composition, chlorophyll-a and primary productivity in Lake Erie Eastern Basin 1973-1975.

($0.75\ g/m^3$) and was represented almost totally by Chrysophyta. Similar with the two previous years, because the diatoms were the dominant group, the chlorophyll and primary productivity did not show any peaks during this time period. Primary productivity did show a slight peak ($10.0\ mg\ C/m^3/hr$) in early June which again corresponded to the dominance of the Cryptophyta.

The second small peak in phytoplankton biomass ($0.69\ g/m^3$) was noted in mid-September (ignoring the December peak for reasons stated previously). Primary productivity ($19.8\ mg\ C/m^3/hr$) and chlorophyll ($5.9\ mg/m^3$) also peaked during this time period. The major group contributing to this biomass was the greens (Chlorophyta).

The apparent trend in primary productivity over the three years was for a slight increase in the Basin mean from 10.3 $mg\ C/m^3/hr$ in 1973 to 11.7 $mg\ C/m^3/hr$ in 1975. This increase paralleled an increase in the Chlorophyta group over the three years (Figure 19). The Cryptophyta also increased slightly when comparing 1973 to 1975 which again parallels with the increase in productivity. The 1974 total dominance by the Cryptophyta (Table 11 and Figure 19) may have been an artifact of our sampling schedule. One of the major peaks of Cryptophyta occurred in late October of 1974. There were no comparable cruises in 1973 or 1975 to detect this peak.

The phytoplankton data were analyzed by stepwise multiple regression analyses to statistically identify relationships between the individual phytoplankton groups and total biomass, primary productivity, and chlorophyll. From the results of these analyses, much of the variation in total phytoplankton biomass was able to be significantly explained by a few of the major groups comprising the total biomass each year. Of the total variation in biomass for 1973 which ranged from $0.66\ g/m^3$ to $1.62\ g/m^3$, 52% could be explained by fluctuations in the Pyrrhophyta (dinoflagellates) and 26% by fluctuation in the Cyanophyta (bluegreens). The bluegreens became much more dominant during the late summer of 1974 and they accounted for 48% of the variation in biomass, which ranged from 0.44 to $3.72\ g/m^3$ during this year. The dinoflagellates accounted for 21% of the variation. Thus, in 1973 and 1974 the dinoflagellate and bluegreen groups accounted for 78% and 70% respectively in total biomass variation. The roles of each group were reversed, however, between the two years.

The Chrysophyta became very important in 1975 compared to the other two years because they accounted for 42% of the variation in total biomass this year. The bluegreens explained 16% of the biomass variation and the greens accounted for 14%. Thus, the dinoflagellates and bluegreens had significantly decreased in terms of their contribution to total biomass and the diatoms (Chrysophyta) had become more powerful in controlling the total biomass variation over the year. Furthermore, the greens were more important in 1975 than either of the other two years.

Munawar and Burns (1976) found that relationships between variables changed significantly with the time of the year. Therefore, looking at relationships of variables contained in data sets covering an entire sampling year sometimes may overshadow the true picture. The data were therefore split into the three seasonal sets of spring, summer and fall (Table 1), and analyzed for each year of the study.

In the spring of 1974 flagellates explained 95% of the variation in total phytoplankton biomass. The spring season was sampled much earlier in 1975 and indicated that the diatoms explained 88% of the variation in total biomass in April of this year.

The summer seasons for the three years also showed numerous variations. The Pyrrhophyta explained 87% of the total biomass variation in 1973 as compared to 67% and 22% being explained by Cyanophyta and Pyrrhophyta, respectively in 1974. In 1975 the Chlorophyta were the dominant summer group explaining 56% of the variation in total biomass. The flagellates explained approximately 29% of this variation.

The fall sampling cruises revealed that diatoms consistently dominated in all three years and explained 43%, 79% and 49% of the variation in total phytoplankton biomass for 1973, 1974 and 1975 respectively. In 1973 the Cyanophyta and Pyrrhophyta explained an additional 38% in the total biomass variation while in 1975 the Cyanophyta and Chlorophyta accounted for 48% of the biomass variation.

Therefore, the information from all three years show that the Chrysophyta are the most important group early in the spring (1975) followed by dominance of the Cryptophyta and flagellates (1974) later in the spring and into early summer. The summer season biomass appears to be controlled by the Pyrrhophyta and Cyanophyta with the Chlorophyta becoming more abundant in 1975. The fall season again shows the dominance of the Chrysophyta in controlling total biomass variation.

In the analyses of the dependent variables of primary productivity and chlorophyll, there were not many significant relationships seen with the phytoplankton groups. The Chlorophyta did explain 33% of the variation in primary productivity over the three years. This would be expected since the Chlorophyta are very photosynthetically active (Munawar and Burns, 1976). Primary productivity as an independent variable explained 15% of the variation in chlorophyll over the three years.

The chlorophyll values for each year varied to a great extent between stations of any cruise. Because there were considerable depth ranges between the stations, the chlorophyll values were placed into two groups, inshore stations (<25 m) and offshore stations (>25 m). As a result of these groupings (Tables 12, 13 and 14) there was a difference observed between the shallow and deeper areas. The shallow stations consistently showed higher mean chlorophyll values than the deeper stations. There was no significant difference, however, between the two means for any year due to the high standard deviations.

Phytoplankton data from the three years were compared to the physio-chemical variables to determine any significant relationships. Over the total three years the general trend in the Basin was a negative correlation between the phytoplankton groups and both pH and specific conductance. During this same period, the phytoplankton were positively correlated with dissolved oxygen. There were no significant correlations between the groups and any of the nutrients for the comparison of the total three year data set. When the data sets were broken up into yearly and seasonal comparisons, however, several strong correlations between nutrients and the phytoplankton were apparent.

The Chrysophyta showed a strong positive relationship with nitrates both in 1973 and 1975. In 1975 this relationship was observed in the spring and fall when the diatoms were most numerous. The diatoms also displayed a positive correlation with total nitrogen in the spring of 1975 and generally showed a negative relationship with temperature over all three years. In general, in their seasons of abundance, the diatoms were positively correlated with dissolved oxygen.

The flagellates showed a strong positive correlation with total nitrogen in both the summer of 1973 and the summer of 1974. They also were positively correlated with dissolved oxygen for several of their peak seasons over the three years.

The Chlorophyta showed a high positive correlation with temperature during the summer season of all three years. In 1974 they were positively correlated with nitrate and in 1975 showed a negative relation to this nutrient. The greens were also negatively related to dissolved oxygen during their peak growth seasons in 1974 and 1975.

The Pyrrhophyta were not significantly correlated with any nutrients but did show a negative correlation with dissolved oxygen in 1974. The Cyanophyta showed a positive relationship with total phosphorus and temperature in 1975 and were negatively correlated with dissolved oxygen both in 1973 and 1975.

Chlorophyll, which is often used as a measure of biomass,

Table 12. INSHORE-OFFSHORE COMPARISON OF
CHLOROPHYLL-a (CORRECTED) MEAN CONCENTRATIONS
(mg/m^3) IN THE EASTERN BASIN OF LAKE ERIE
JULY - DECEMBER 1973

Cruise	Date	Mean	SD	<25m	SD	>25m	SD
II	4-10 July	2.75	1.49	3.35	1.62	2.04	0.95
III	10-16 July	4.80	2.30	5.60	2.33	3.66	1.83
IV	31 July - 6 August	4.74	1.63	5.29	1.94	4.14	0.99
V	15-20 August	4.30	1.17	4.45	1.41	4.10	0.83
VI	11-15 September	3.76	1.73	4.15	2.08	3.35	1.30
VII	1-4 October	6.59	1.92	7.23	2.40	5.89	0.86
VIII	8-11 October	6.40	1.35	6.38	1.39	6.48	1.37
IX	22-26 October	6.44	2.70	7.08	1.22	5.75	3.65
X	8-12 December	3.48	1.08	-	-	-	-
Year	1973	4.90	2.23	5.37	2.20	4.38	2.16

Table 13. INSHORE-OFFSHORE COMPARISON OF CHLOROPHYLL-a (CORRECTED) MEAN CONCENTRATIONS (mg/m^3) IN THE EASTERN BASIN OF LAKE ERIE MAY - DECEMBER 1974

Cruise	Date	Mean	SD	<25m	SD	>25m	SD
IV	21 May - 1 June	7.11	5.48	7.30	5.94	6.88	5.13
VI	18-22 June	4.97	2.58	4.60	3.30	5.35	1.39
VIII	26-30 July	3.33	1.78	3.90	2.08	2.60	0.97
XI	6-9 September	4.25	1.32	4.65	1.47	3.78	0.97
XIV	23-27 October	7.14	1.49	7.21	1.21	7.03	1.92
XVI	19 November - 5 December	3.91	1.23	4.35	1.35	3.39	0.85
Year	1974	5.11	3.12	5.36	3.28	4.80	2.90

Table 14. INSHORE-OFFSHORE COMPARISON OF CHLOROPHYLL-*a* (CORRECTED) MEAN CONCENTRATIONS (mg/m^3) IN THE EASTERN BASIN OF LAKE ERIE APRIL - DECEMBER 1975

Cruise	Date	Mean	SD	<25m	SD	>25m	SD
I	9-12 April	3.24	1.76	3.78	2.11	2.71	1.18
II	2-5 June	2.46	0.82	2.59	0.95	2.29	0.63
III	25-29 July	2.98	1.05	3.51	1.05	2.36	0.64
IV	15-18 September	5.88	2.09	6.48	2.71	5.19	0.51
V	7-9 December*	3.63	0.83	3.77	1.02	3.51	0.66
Year	1975	3.66	1.90	4.06	2.22	3.21	1.35

* PARTIAL CRUISE (15 stations)

was the only phytoplankton parameter that displayed any significant correlation with dissolved phosphorus. In 1973 and 1974 a strong positive relationship existed between these two variables. In 1973 chlorophyll was negatively correlated with total nitrogen and in 1975 it was negatively correlated with nitrate and positively to ammonia.

The mean phytoplankton group composition on a basinwide scale for the five groupings of stations (Figure 10) derived from discriminant analysis of the physio-chemical variables is shown in Figure 20. In general the southern shore stations and western end of the Basin showed a higher percentage of diatoms over the three years, whereas the midlake and northern shore stations possessed the highest percentage of bluegreens. Station 21 didn't really show a dominance of any one group of phytoplankton. Figure 20 indicated that the dinoflagellates were very high in number at the eastern end of the Basin and along the Canadian shore.

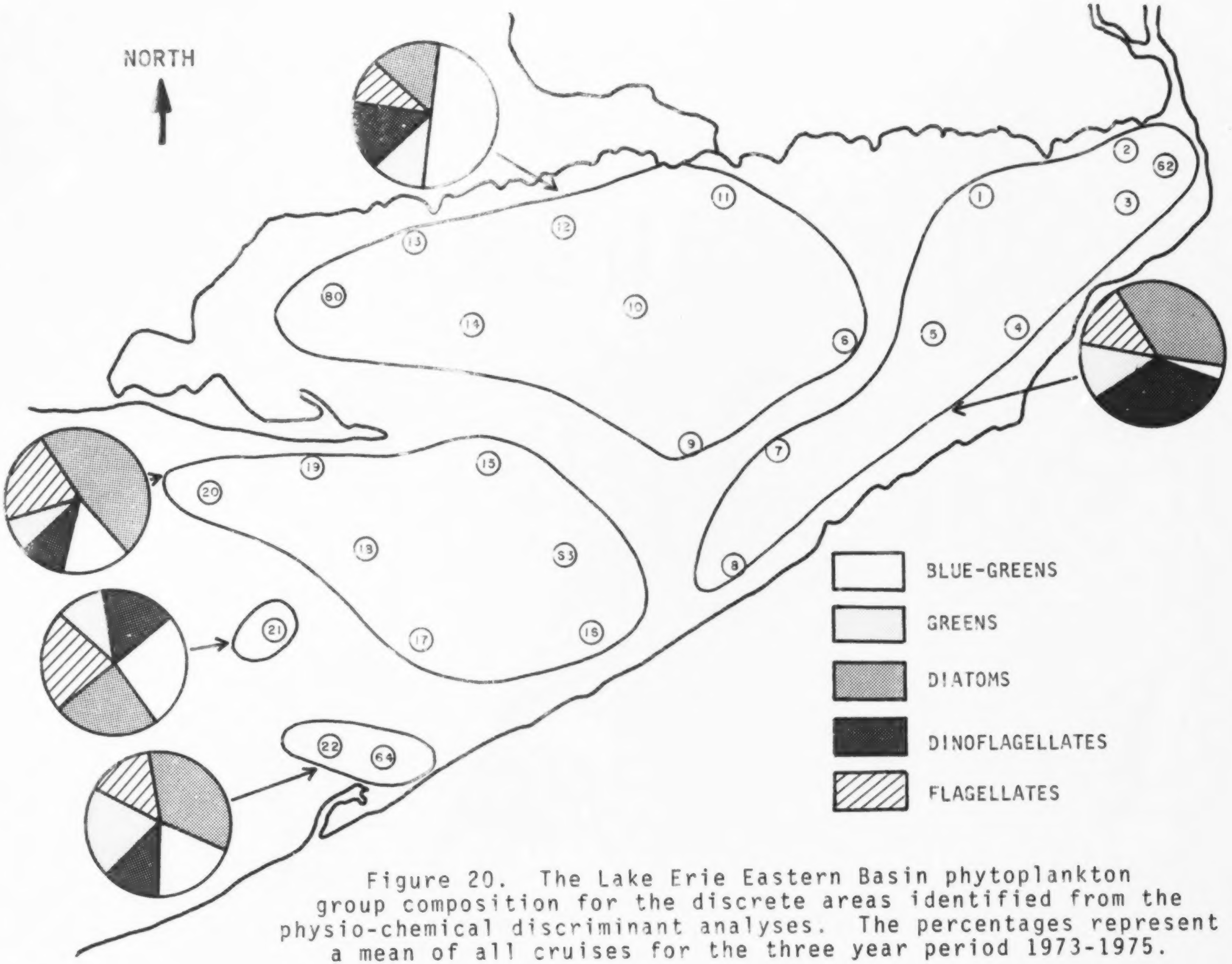
ZOOPLANKTON

The detailed listings of species of crustacean zooplankton encountered in the Eastern Basin of Lake Erie from 1973 to 1975 are found in the Annual Reports (Great Lakes Laboratory, 1974; 1975; 1976). For purposes of this report, zooplankton cells is equated with zooplankton numbers.

The horizontal distribution of crustacean zooplankton in the waters of the Eastern Basin during 1973, 1974 and 1975 are shown in Figure 21. The same trend exhibited by the phytoplankton was also displayed by the zooplankton mean number over the Basin for the three years of the study. There was a much higher level of total numbers seen in 1974 compared to the other two years. The general range in the Basin in 1974 was from 7-12 x 10^4 #s/m^3 compared to 3-9 x 10^4 #s/m^3 in 1973 and 3-7 x 10^4 #s/m^3 in 1975.

In 1973 the higher concentrations of zooplankton appeared to be in the area of Long Point Bay and in the waters off the south shore near Dunkirk. In 1974 the eastern end of the Basin showed extremely high numbers of cells as did the area of Dunkirk again. The distribution of organisms in 1975 was similar in pattern to 1974 except that the higher concentrations off Dunkirk had shifted slightly west toward Barcelona. There was also a slight influence from the Central Basin and the Harbor of Erie noted at Stations 22 and 64.

The yearly trends in zooplankton numbers for the three years and the associated group composition are illustrated in Table 15. Again, as depicted by the horizontal distributions, there was a large increase in mean total number (8.43 x 10^4) for 1974 compared to either of the other two years. There appeared to be a slight decline in the three adult groups of zooplankton



NORTH
BLUE-GREENS
GREENS
DIATOMS
DINOFLAGELLATES
FLAGELLATES
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3
4
5
6
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10
11
12
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14
15
16
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21
22
53
62
64
80

Figure 20. The Lake Erie Eastern Basin phytoplankton group composition for the discrete areas identified from the physio-chemical discriminant analyses. The percentages represent a mean of all cruises for the three year period 1973-1975.

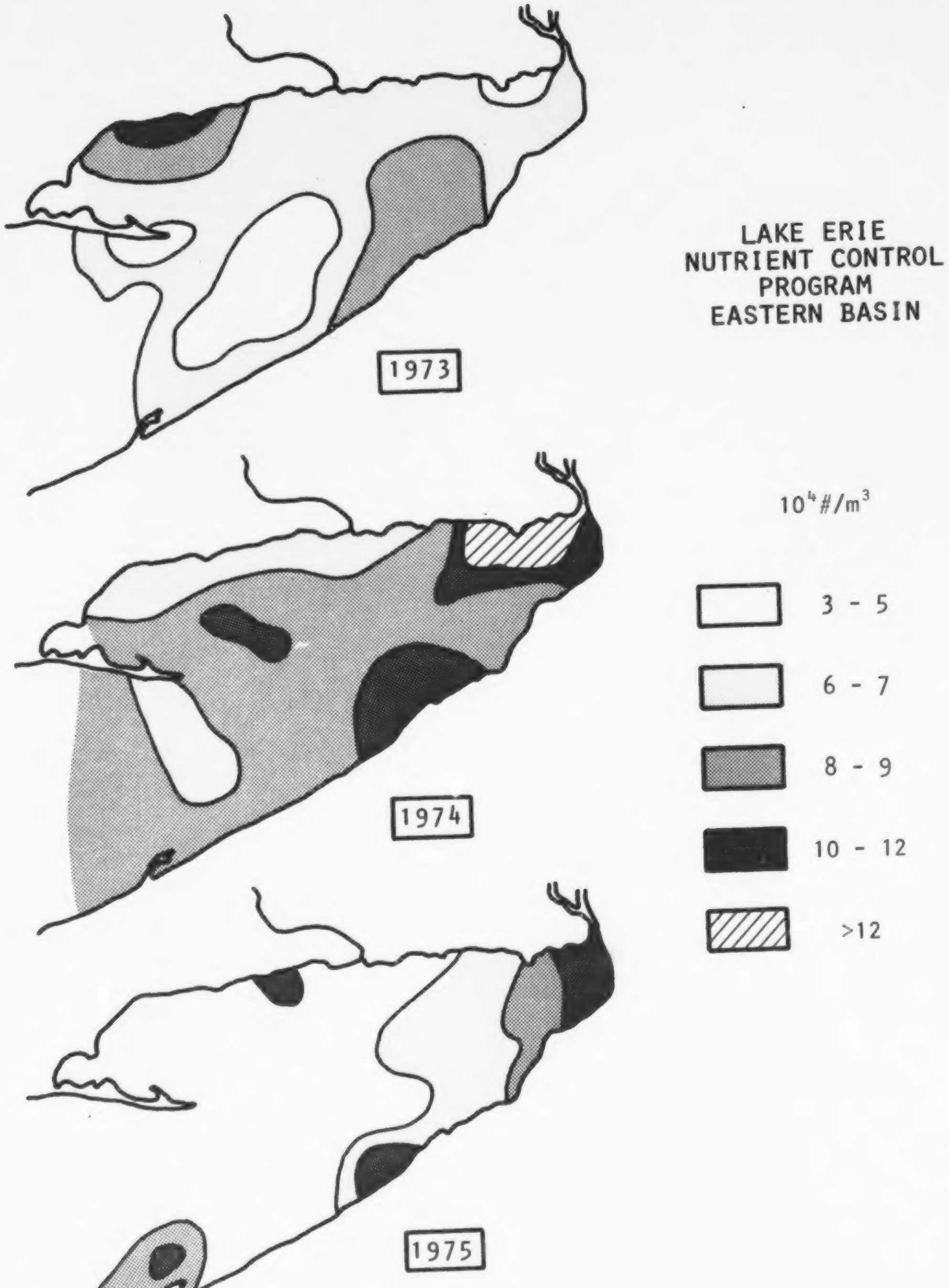

LAKE ERIE
NUTRIENT CONTROL
PROGRAM
EASTERN BASIN
1973
1974
1975
10⁴#/m³
3 - 5
6 - 7
8 - 9
10 - 12
>12

Figure 21. Lake Erie Eastern Basin mean horizontal distribution of crustacean zooplankton biomass 1973-1975.

Table 15. MEAN VALUES ($\#/m^3$) OF CRUSTACEAN ZOOPLANKTON AND ITS % COMPOSITION FOR ALL SAMPLING CRUISES IN LAKE ERIE EASTERN BASIN 1973-1975.

	1973					1974						1975				
Cruise #	II	IV	VII	VIII	X	IV	VI	VIII	XI	XIV	XVI	I	II	III	IV	V
Date	Jul 4-10	Jul 31-Aug 6	Sep 11-15	Oct 1-5	Dec 8-12	Jun 4-7	Jun 18-22	Jul 26-30	Sep 6-9	Oct 23-27	Nov 19-Dec 5	Apr 9-12	Jun 2-5	Jul 25-29	Sep 15-18	Dec 7-21
Zooplankton (10^4 $\#/m^3$)	13.50	7.28	3.71	3.31	1.02	7.35	27.38	8.42	2.33	2.85	2.24	0.72	16.12	7.71	2.68	0.71
Yearly mean					5.76						8.43					5.59
							% Composition									
Cladocera	24.17	21.53	23.23	31.53	25.77	2.06	40.26	19.25	22.50	36.62	21.52	3.78	31.10	16.30	31.82	15.79
mean annual %					25.25						23.72					19.76
Calanoida	13.08	13.91	11.46	9.15	3.75	0.73	0.78	9.90	14.60	9.85	7.61	1.70	1.30	16.82	7.94	8.06
mean annual %					10.27						7.25					7.16
Copepod nauplii	32.67	20.58	27.99	24.91	27.59	73.76	20.04	21.17	30.51	23.23	26.21	60.01	36.04	34.73	35.24	31.63
mean annual %					26.75						32.49					39.53
Cyclopoida	30.08	43.98	35.32	34.41	42.89	23.45	38.91	49.68	32.39	30.32	45.46	34.42	31.56	32.15	25.00	44.52
mean annual %					37.34						36.70					33.53
CALANOID : CYCLOPOID + CLADOCERA Ratio (yearly mean)*					0.16						0.11					0.11

* Eutrophication index for crustacean zooplankton (Patalas 1972)

(Cladocera, Calanoida and Cyclopoida) over the three years and an increase in the copepod nauplii. This trend may have been an artifact of the sample analysis, however, since the expertise in taxonomy of the nauplii had improved from 1973 to 1975. Therefore, when one considers only the adult group composition, there was essentially no change between the three years.

The seasonal patterns of mean total number and group composition (Figure 22) showed that the peak of zooplankton numbers usually occurred in late June and early July of all three years. During this season the cyclopoids and cladocerans were represented almost equally in number. The calanoids, on the other hand, only represented 1 to 13% of the total cell number. Over the three year seasonal trends, the calanoids never were dominant and usually reached their peak in the middle of the summer season (late July - early September).

The copepod nauplii generally displayed an early peak in the spring (1974 and 1975) and then showed a progressive decline through the remainder of the year. This group never represented less than 20% of the total zooplankton and reached maximums of over 60% of the total number during the spring peaks.

There was a strong negative correlation exhibited between the cladocerans and cyclopoids when each was compared to phytoplankton biomass. There were not many significant correlations between the zooplankton groups and the phytoplankton groups. The calanoids, however, did show a positive correlation with diatoms and bluegreens. Although not significant, there was generally a negative relationship between any one of the zooplankton groups and total phytoplankton biomass.

There were also several relationships between the zooplankton groups and some of the physio-chemical variables. The calanoids were negatively correlated with pH and specific conductance and positively related to dissolved oxygen. The cladocerans were also negatively correlated with conductivity. Furthermore, they were positively correlated with the nutrients of ammonia and total phosphorus. The cyclopoids were positively correlated with temperature.

The mean group composition of zooplankton on a basinwide scale for the physio-chemical station groupings (Figure 10) is shown in Figure 23. The southern shore stations definitely showed dominance of Cladocera over the three years studied. The midlake and most western stations displayed dominance of Cyclopoida and the smallest proportion of Calanoida. The northern shore stations were dominated by Cyclopoida but had a higher number of cladocerans, as did Station 21.

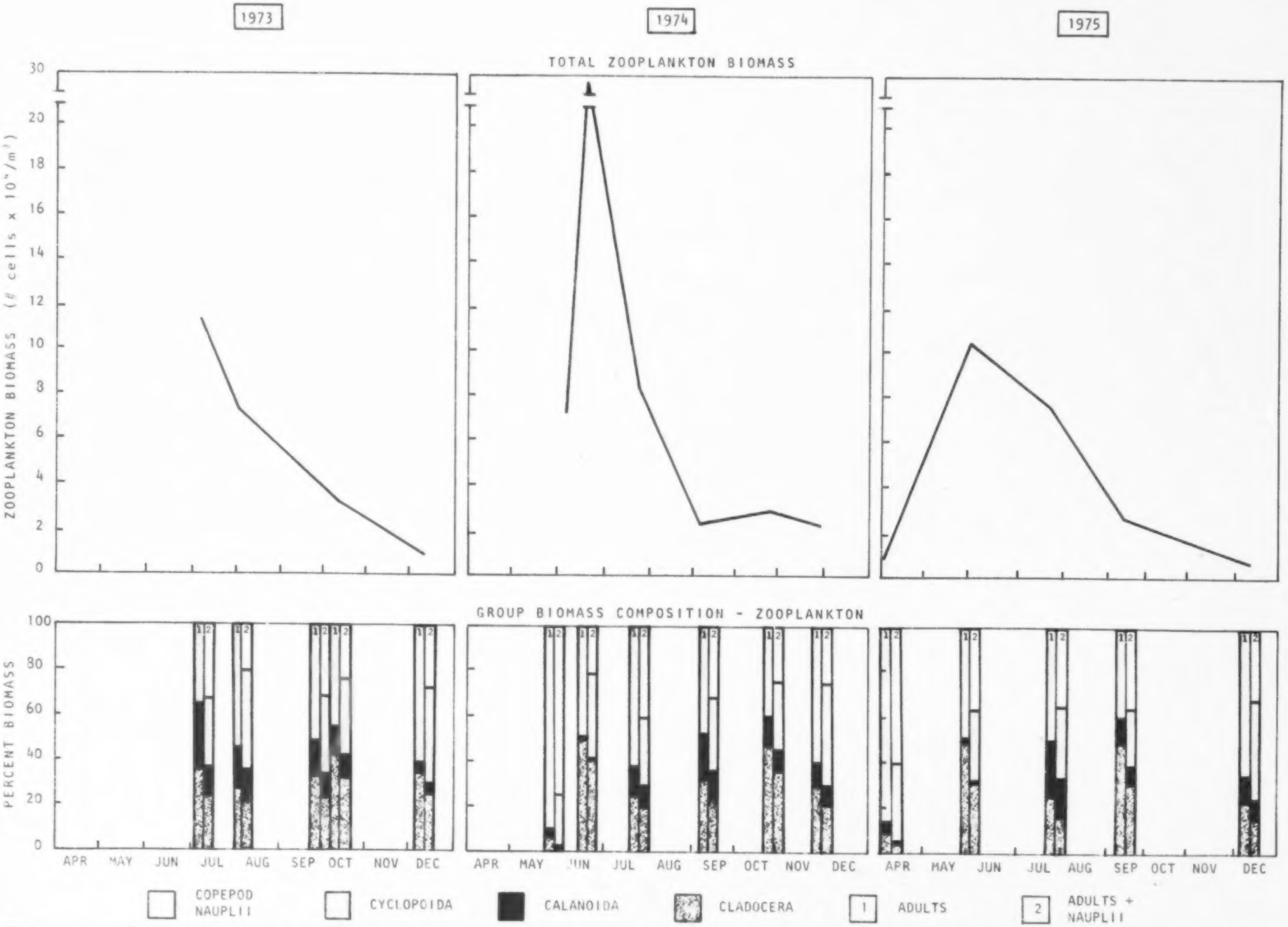
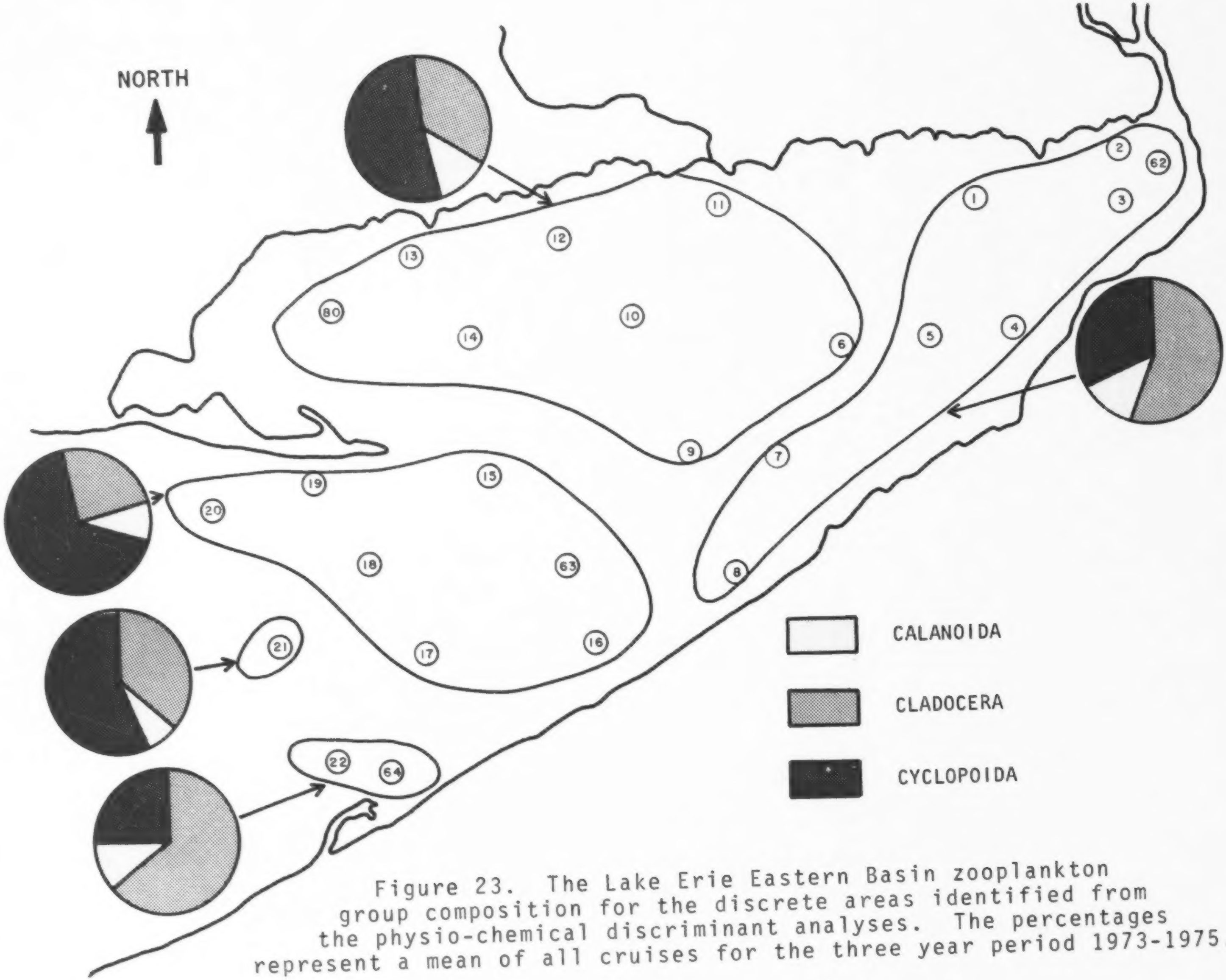


Figure 22. Seasonal fluctuations of crustacean zooplankton biomass and its group composition in Lake Erie Eastern Basin 1973-1975. The group composition at each sampling date are illustrated for both adults and adults plus copepod nauplii.


NORTH
2
62
1
3
11
12
13
80
14
10
6
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4
9
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19
15
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18
63
8
21
17
16
22
64
CALANOIDA
CLADOCERA
CYCLOPOIDA

Figure 23. The Lake Erie Eastern Basin zooplankton group composition for the discrete areas identified from the physio-chemical discriminant analyses. The percentages represent a mean of all cruises for the three year period 1973-1975.

EASTERN BASIN BENTHIC COMMUNITIES

The species listings for the benthic macroinvertebrates encountered in the Eastrn Basin of Lake Erie from 1973 to 1975 are detailed in the Annual Reports (Great Lakes Laboratory, 1974; 1975; 1976). The total number of species encountered each year were 53, 68, and 65 in 1973, 1974, and 1975 respectively. The oligochaetes and amphipods comprised 81% of the total numbers of organisms in 1973. In 1974, the oligochaetes, amphipods and fingernail clams (Sphaeriidae) accounted for 89% of the total numbers. These same three groups comprised 82% of the total organismal numbers in 1975.

The break-down of percent group composition for the major groups observed in the Eastern Basin for each station over the duration of this study is illustrated in Table 16. Additionally the mean number of species observed and the mean total number of organisms (#/m^2) for each station is also shown. The total number of organisms ranged from a low of 1393.9/m^2 at Station 11 to a high of 29,138.0/m^2 at Station 19. Considering the general patterns within the Basin, the Canadian Stations (11, 12, 13, and 80) displayed fewer total numbers of organisms than most other areas but showed higher mean numbers of species encountered. The southern midlake stations and western stations (6, 7, 10, 16, 19, 20, 21) consistently produced a high mean count of total organisms and except for Stations 10 and 19, displayed a relatively high number of species present. The eastern Stations (1, 2, 3, 4, 5, 62) showed a much lower number of total organisms than the midlake and western stations but displayed extremely high mean numbers of species encountered (14-18).

The group compositions for the individual stations (Table 16) showed some interesting trends. The Oligochaeta were the major group at most stations except the northern shore stations. The Amphipoda, as a group, were much more numerous at the midlake and northern stations while the Sphaeriidae were high both on the Canadian side of the Basin and at the eastern end. The Nematoda and Chironomidae showed a similar pattern of higher numbers on the northern and eastern stations. The Isopoda were most numerous on Stations 6, 11, 12, 13, 17, and 21.

Ordination of the benthic data collected for each year of this project showed very little variation between years in the benthic environment of the Eastern Basin. Therefore, ordination of the raw benthic counts for each station on each cruise over the three year duration was performed to produce a composite picture of the different community types in the Eastern Basin of Lake Erie. Plots of the stations along three ordination axes (X, Y, and Z) are given in Figure 24. These plots showed that most variation among the stations was along the X and Y axes. There was much less scatter along the Z-axis and this additional information contributed little to the final groupings of stations.

Table 16. TOTAL MEAN BENTHIC BIOMASS ($\#/m^2$), % GROUP COMPOSITION AND TOTAL NUMBER OF SPECIES ENCOUNTERED FOR EACH LAKE ERIE EASTERN BASIN STATION 1973-1975.

Station	1	2	3	4	5	6	7	8	9	10	11	12	13
Oligochaeta	54.2	45.1	60.1	54.4	62.1	62.9	42.7	50.2	76.7	52.6	35.2	15.1	17.1
Amphipoda	0.6	3.5	3.6	4.0	1.0	4.9	37.6	3.8	17.4	33.6	4.7	29.5	30.0
Sphaeriidae	19.1	114.5	10.8	10.4	18.2	8.3	14.1	18.1	3.5	11.2	30.4	22.0	28.4
Nematoda	7.2	7.0	3.2	3.4	2.2	-	-	0.7	0.6	0.1	3.6	3.2	4.6
Chironomidae	11.0	9.7	8.9	13.6	7.1	1.1	1.6	10.9	0.1	0.1	6.6	8.6	3.9
Isopoda	4.3	-	-	0.1	7.8	22.0	2.5	3.9	0.1	0.1	13.5	13.1	7.9
Mean total # species encountered	16	18	15	15	14	12	14	10	11	9	9	14	17
Mean $\#/m^2$	6420.1	4543.8	3182.5	2067.1	5944.8	10027.8	17582.8	4895.9	7821.2	11833.3	1393.9	3673.4	3803.8

Station	14	15	16	17	18	19	20	21	22	62	63	64	80
Oligochaeta	62.6	80.7	38.6	32.8	50.8	94.2	43.7	43.0	86.0	30.9	65.9	54.9	24.8
Amphipoda	29.0	15.5	47.2	32.6	35.8	0.6	18.3	25.4	1.2	4.1	18.7	1.4	19.5
Sphaeriidae	5.5	2.3	9.3	10.8	6.4	2.4	17.4	18.8	6.1	22.8	6.6	6.2	32.6
Nematoda	1.1	-	0.3	1.5	1.0	0.1	12.3	1.9	0.6	6.9	1.1	1.2	13.6
Chironomidae	1.1	0.5	1.6	1.9	2.3	0.5	2.9	0.9	5.2	8.7	3.6	4.6	7.4
Isopoda	-	-	2.2	7.9	0.3	2.1	4.7	9.5	0.8	0.1	0.9	7.4	2.7
Mean total # species encountered	9	9	13	12	8	9	16	11	13	14	12	17	17
Mean $\#/m^2$	8691.8	7795.6	16933.2	7924.0	7345.6	29138.0	12443.8	11290.0	4939.0	3242.8	5557.8	10842.0	5892.7

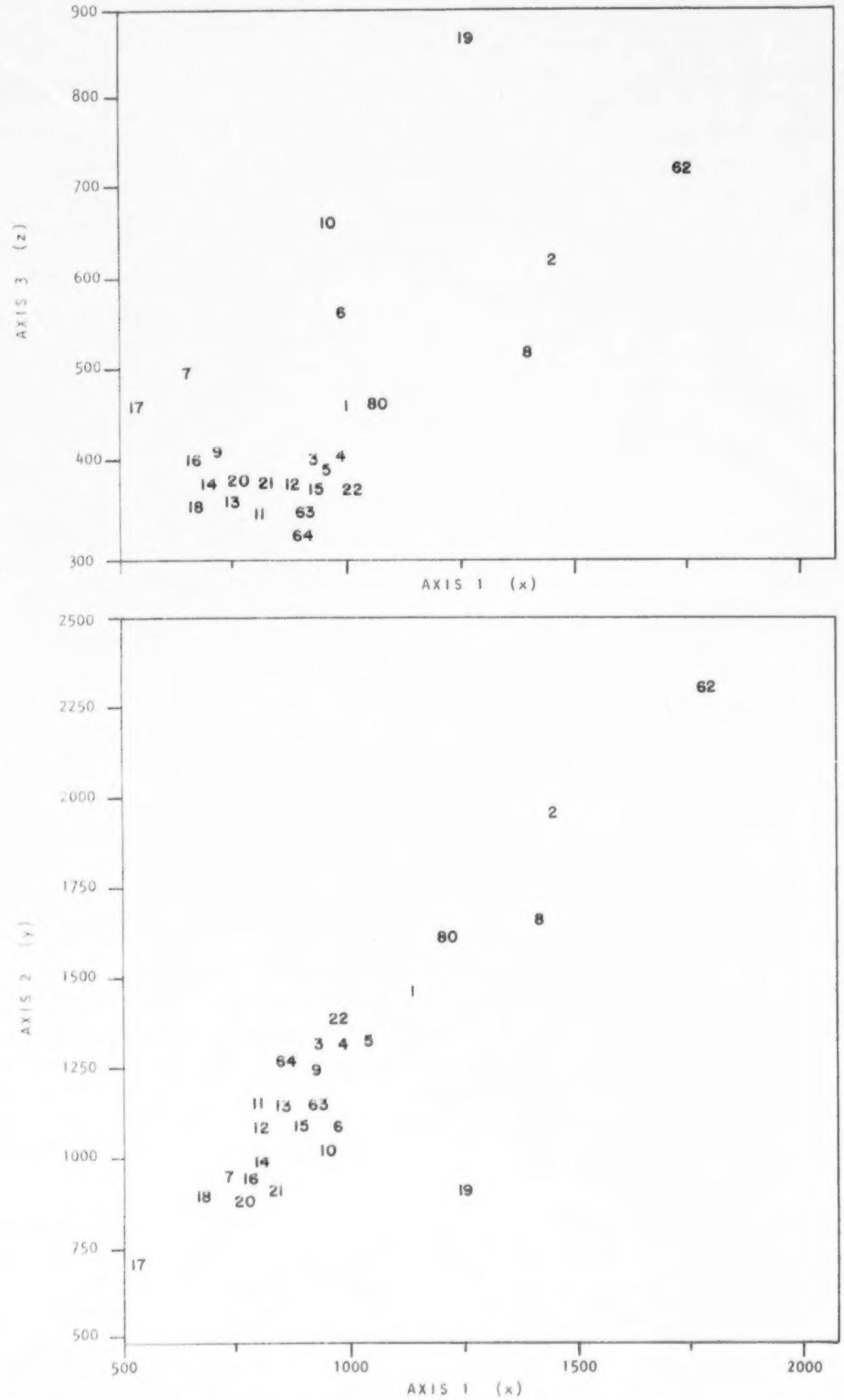

Figure 24. Community ordination of the benthic macroinvertebrate groups in Lake Erie Eastern Basin 1973-1975. Numbers represent stations. Axis values are in ordination units. Distance between stations reflect community similarity.

Discriminant analysis of the community ordination coordinates (x, y, and z) produced the grouping of stations seen in Figure 25. These groupings were very similar to the ordination results (Figure 24) providing an additional check on our separation of stations. This information plus the community ordination results (Figure 24) and the actual listings describing the major species for each station during the study period were critically examined to derive community types within the Eastern Basin. To characterize the Basin by different community types, which may offer additional information concerning water quality, many of the discrete areas of the Basin were described in terms of "rarer" species (Table 17) in addition to the dominant worms and crustaceans. This description, which follows, is illustrated via Figure 24 and Table 17.

The most eastern area of the Basin represented by Stations 2 and 62 displayed a benthic community comprised of oligochaetes, both mature and immature, and bivalves. *Pisidium* was the numerically dominant bivalve in this area along with the presence of the oligochaetes *Peloscolex ferox* and *Potamothrix vejdovskyi*. The nematode *Dorylaimus* and the gastropod *Valvata* were also an important component of this community.

The next area, also at the eastern end of the Basin, and in close relation to Stations 2 and 62, was the group represented by Stations 1, 3, 4, and 5. Again the oligochaetes (*P. ferox*) and the bivalves (*Pisidium*) showed a dominance in the community. The chironomid group, however, showed increasing numbers in this area of the Basin. *Valvata* also displayed much more of an increase, especially at Stations 3 and 4. The isopod *Asellus* was numerous at Stations 1 and 5 on several cruises.

Station 8, as illustrated in Figure 24, was completely separated from the other areas of the Basin. This station showed very low total counts for all organisms during most of the cruises and displayed a very high number of Chironomidae, especially *Procladius*. The dominant members of the community were the bivalves *Pisidium* and *Sphaerium* and the tubificid *Aulodrilus pluriseta*. Similar to Stations 1 and 5, the isopods increased in number at this location.

The northern shore Stations (11, 12, 13) were primarily characterized by an amphipod-bivalve community. The amphipod *Pontoporeia affinis* and the fingernail clams *Pisidium* and *Sphaerium* were the most abundant organisms encountered. Additionally the nematode *Dorylaimus* was very common, especially at Stations 12 and 13. The chironomids and oligochaetes were prevalent at Station 11.

As illustrated in the ordination plots (Figure 24), Station 6 separated from most other areas on the X-Z axes. The species list for this area also indicated it was relatively

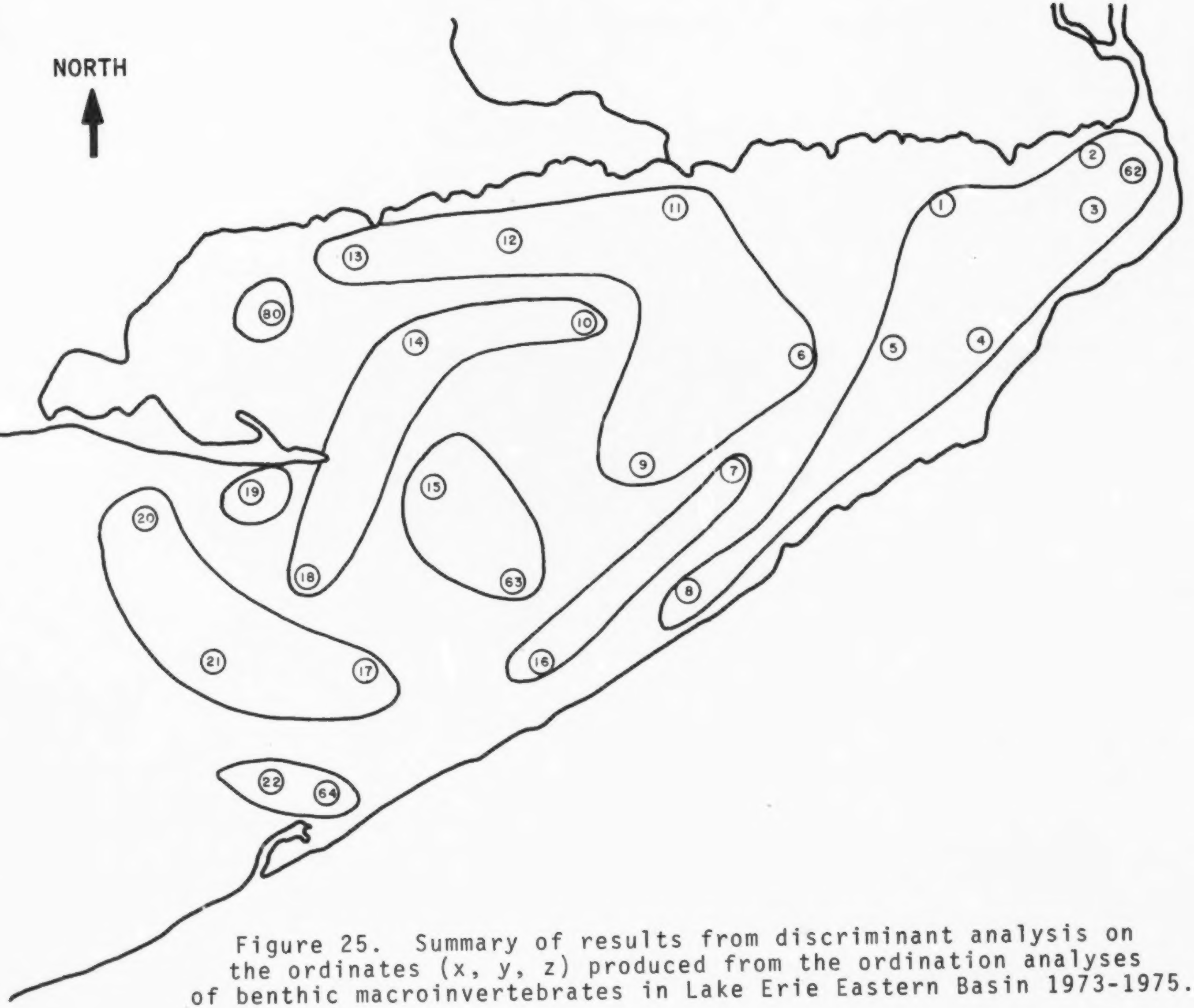
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Figure 25. Summary of results from discriminant analysis on the ordinates (x, y, z) produced from the ordination analyses of benthic macroinvertebrates in Lake Erie Eastern Basin 1973-1975.

Table 17. CLASSIFICATION OF EACH LAKE ERIE EASTERN BASIN STATION ACCORDING TO A BENTHIC COMMUNITY-TYPE.

· Species included for each station under its community type are additional organisms encountered in high numbers for that station.

Station	Oligochaet-Bivalve *Pisidium-Peloscolex*	Oligochaet-Bivalve *Pisidium-Aulodrilus*	Amphipod-Bivalve *Pontoporeia-Pisidium*	Amphipod-Bivalve *Pontoporeia-Sphaerium*	Oligochaet-Isopod *Potamothrix-Asellus*
1	*Asellus*, *Procladius*				
2	*Dorylaimus*, *Valvata*				
3	*Valvata*, *Procladius*				
4	*Valvata* *Procladius*				
5	*Asellus*, *Procladius*				
6					*Pisidium*, *Pontoporeia*, *Potamothrix*
7			*Potamothrix*, *Peloscolex*, *Limnodrilus*, *Asellus*		
8		*Sphaerium*, *Asellus*, *Procladius*			
11			*Peloscolex*, *Asellus*, *Procladius*		
12			*Asellus*, *Dorylaimus*, *Gammarus*, *Procladius*		
13			*Sphaerium*, *Asellus*, *Dorylaimus*		
16			*Potamothrix*, *Asellus*, *Stylodrilus*, *Sphaerium*		
17			*Stylodrilus*, *Asellus*, *Peloscolex*, ostracods		
20			*Dorylaimus*, *Potamothrix*, *Stylodrilus*, *Asellus*		
21			*Asellus*, *Peloscolex*, *Stylodrilus*, *Sphaerium*		
62	*Dorylaimus*, *Valvata*				
80				*Dorylaimus*, *Aulodrilus*, *Gammarus*, *Potamothrix*	

Station	Oligochaet-Amphipod *Stylodrilus-Pontoporeia*	Oligochaet-Chironomid *Limnodrilus-Procladius*	Oligochaet *Limnodrilus-Tubifex*	Oligochaet-Amphipod *Limnodrilus-Pontoporeia*
9				*Potamothrix*, *Pisidium*, *Tubifex*, *Peloscolex*
10	*Pisidium*, *Limnodrilus*, *Potamothrix*			
14	*Pisidium*, *Limnodrilus*, *Potamothrix*			
15				*Potamothrix*, *Tubifex*, *Pisidium*, ostracods
18	*Pisidium*, *Limnodrilus*, *Potamothrix*			
19			*Pisidium*, *Asellus*, *Pontoporeia*	
22		*Potamothrix*, *Aulodrilus*, *Sphaerium*		
63				*Pisidium*, *Peloscolex*, *Tubifex*, ostracods
64		*Aulodrilus*, *Asellus*, *Pisidium*		

discrete. The major community components were the isopod *Asellus* and the oligochaet *P. vejdovskyi*. In species' lists this station showed some resemblance to the northern shore stations (especially 11) and the area represented by Stations 1, 3, 4, and 5. Station 6 discriminated itself from Station 11, however, by the lack of Chironomidae and similarity from Stations 4 and 5 by higher numbers of isopods and lack of the gastropod *Valvata*.

The area of Long Point Bay (Station 80) was also comparably different from other areas of the Basin (figure 24). This habitat was almost totally dominated by the bivalve-amphipod grouping with *Sphaerium*, *Pontoporeia* and *Gammarus* comprising the bulk of the community. The nematode *Dorylaimus* and the oligochaete (*Aulodrilus*) were also a major component of the area. Because of the large *Sphaerium* number, Station 80 did show some relationship to Station 13.

The midlake Stations (10, 14, 18) displayed a community composed primarily of the amphipod *P. affinis* and the oligochaete *Stylodrilus heringianus*. There were also a number of the bivalve *Pisidium* seen during most cruises of the study. The other midlake Stations (9, 15, 63) also showed *P. affinis* in high numbers but instead of *S. heringianus*, displayed *Limnodrilus* and *Peloscolex* as very numerous. Additionally, this area had a high number of ostracods and *Tubifex tubifex*.

The western end of the Basin (7, 16, 17, 20, and 21) indicated the dominance again of the amphipods and bivalves, *P. affinis* and *Pisidium*, with fewer oligochaetes observed. *Sphaerium* also was quite numerous. The isopod *Asellus* was represented at all the stations and several of the stations showed the occurrence of the oligochaet *Peloscolex* in relatively high numbers.

The area of the Basin off Erie, Pa. (Stations 22 and 64) was dominated by the oligochaetes *Limnodrilus*, *Aulodrilus* and *Potamothrix*. The chironomids were also present in relatively high numbers in this area. The isopod *Asellus* occurred at Station 64 and the bivalves *Sphaerium* and *Pisidium* at Stations 22 and 64 respectively.

Similar to Station 8, Station 19 was completely separated from all other areas of the lake in the ordination plot (Figure 24). This station was characterized almost completely by *Tubifex tubifex* and a large majority of immature oligochaetes many of which were *Limnodrilus*. This area probably showed the highest concentration of oligochaetes in the entire Basin.

SECTION 6

DISCUSSION

The basinwide epilimnetic distributions of the major chemical nutrients described in this report illustrate that in general the Eastern Basin phosphorus concentrations did not vary significantly. Total and dissolved phosphorus displayed seasonal fluctuations but remained relatively constant between the three years. Total phosphorus ranged annually from a mean of 22.3 to 30.6 μgP/l. Dissolved phosphorus showed a slight increase from annual means of 4.3 μgP/l in 1973 to 7.4 μgP/l in 1975. Concentrations of these forms of phosphorus were comparable to values observed in 1970 (Burns, 1976). The 1970 study illustrated ranges for total phosphorus in the Eastern Basin of between 18 and 32 μgP/l depending upon season of the year. The 1970 study didn't measure dissolved phosphorus but did report particulate phosphorus (total P - dissolved P). These values ranged from approximately 9 to 18 μgP/l for the Eastern Basin epilimnion over a yearly cycle. The range in particulate phosphorus for the three year study described here was approximately 15 to 26 μgP/l, a slight increase over 1970. Due to the large standard deviations associated with the means of the three year study, no real differences in phosphorus concentrations can be demonstrated between the 1970 results and those from the GLL 1973-1975 survey.

Changes in concentrations for several epilimnetic nitrogen forms contrasted sharply with those for phosphorus. All nitrogen compounds displayed an increase in 1974 as contrasted with 1973 and 1975. This change was most notable for ammonia which varied from a Basin mean of 73 μgN/l in 1973 to 203 μgN/l in 1974. In 1975 this nutrient decreased again to a mean of 38 μgN/l, very close to the mean value of 28 μgN/l observed in 1970 (Burns, 1976).

The discriminant analysis of physio-chemical variables over the three years for each station (Table 5) further illustrated the variation for ammonia concentrations. The variations in nitrogen were primarily the result of annual fluctuations in ammonia concentrations possibly caused by localized inputs into the Basin. Most of the stations that showed variability due to ammonia (e.g. 4, 8, 11, 13) were located in the vicinity of a major tributary. Furthermore, Stations 18 and 21 also showed variability in ammonia that was the result of entrainment from the Central Basin (Great Lakes Laboratory, 1976).

In the past, ammonia was usually relatively constant over a yearly cycle in this system and the nitrate-nitrite concentrations showed the greater variations (Burns, 1976). In the present study relatively low levels of ammonia were seen throughout the year (except 1974) and high levels of nitrate-nitrite in the spring were followed by decreased levels in the summer and fall (Table 4). Furthermore, the phytoplankton annual biomass reflected the above. The higher ammonia levels seen in 1974 may have produced increased biomass levels of phytoplankton.

The preceding observations can be explained by the following. Ammonia is the preferred form of nitrogen for phytoplankton uptake (Healy, 1973). Thus the ammonia increases in 1974, due to localized inputs, increased the phytoplankton biomass. Furthermore, it appeared that the greater biomasses of phytoplankton being produced in later summer and early fall (Figure 19) required more ammonia than was available with the result that nitrate was utilized and decreased in the epilimnion as observed (Table 4). The large decrease in ammonia concentrations in 1975 may have also been related to the change in bluegreen algae concentrations. The 1973 and 1974 ammonia values were relatively high compared to those reported by Burns (1976). As stated above the higher values during 1974 were compounded by localized inputs of ammonia. For both these years, however, bluegreen algae comprised a mean of approximately 12% of the total phytoplankton biomass. The ammonia could remain in adequate supply because of nitrogen fixation by the blue-green algae (Howard et al., 1970) and their subsequent decomposition resulting in ammonia regeneration. The bluegreens were largely absent in 1975 when the strong local inputs of ammonia were not observed (Figure 5). Thus ammonia levels were much lower and in close agreement with 1970 values (Burns, 1976).

The observed dynamics of nitrogen and phosphorus in this system over the three year duration raised an additional question. What nutrient is limiting in the Eastern Basin? In most cases a nutrient becomes limiting under a specific set of circumstances including the presence of certain phytoplankton species and the appropriate ratio of mineral nutrients in the system. Consequently, when the equilibrium is upset by excessive inflows of a particular essential nutrient, the ratios of the more important factors (phosphorus, nitrogen, etc.) can be disrupted. As a result species may change, and eventually a new steady state is obtained where one limiting factor is replaced by another. Titman (1976) found this to be the case with two diatom species and the ratio between silica and phosphate.

For years phosphorus has been characterized as the limiting factor in Lake Erie (Vollenweider, 1968; International Lake Erie Water Pollution Board, 1969; Dobson et al., 1974). Excessive stimulation of phytoplankton productivity and the trend towards more eutrophic conditions within Lake Erie are believed to have been the result of increases in phosphorus loadings. The possibility now exists, however, where phosphorus may no longer be the limiting factor in the Eastern Basin. With 50% average increases (Verduin, 1969) in phosphorus loadings, the ratio of phosphorus to nitrogen may have shifted enough to create a new steady state in which nitrogen has replaced phosphorus as the limiting factor. This supposition is reinforced by findings from this three year study. The nitrogen concentrations, especially ammonia, showed a large increase in 1974 with very little change in phosphorus concentrations (Figures 2, 3, and 5). The phytoplankton biomass also showed a large peak during this year (Figure 19) compared to 1973 and 1975. Thus it would appear that the increase in nitrogen had some effect upon the system.

It must be understood that the above is based solely on the facts at hand. There is the possibility that because of the cruise schedules much of the data concerning phytoplankton peaks and nutrient increases observed in 1974 were simply missed in 1973 and especially in 1975. Furthermore, it must be emphasized that while there were no apparent changes in phosphorus concentrations represented by total and dissolved phosphorus, the phosphorus component directly utilized by phytoplankton (orthophosphorus) was not measured. Simply because phosphorus change was not observed, one can not be sure that in fact a change in orthophosphorus did not take place and was not highly contributive.

Another factor that also may have influenced the observed increases in nitrogen in 1974 was the instability of the thermocline. As mentioned previously, the breakdown of the thermocline during the periods of peak stratification in the Eastern Basin was a common occurrence as a result of summer storms and internal seiches. Furthermore, many of the nutrients including carbon and nitrogen, displayed uniform values throughout much of the water column in 1974 (Great Lakes Laboratory, 1975), indicating the lack of a chemocline and the instability of stratification during the sampling cruises. These observations were made in contrast to 1975 data where definite chemoclines were seen on the sampling cruises (Great Lakes Laboratory, 1976). Thus, the instability of stratification in 1974 may have further contributed to the higher observed values of nutrients such as nitrogen due to the constant recycling of the epilimnetic-hypolimnetic waters.

The apparent instability of stratification over periods of this study compounded by the large volume of hypolimnetic waters also had a direct effect on the oxygen depletion of the Eastern Basin. The calculations presented (Tables 6-9) indicated that the oxygen demand of the Eastern Basin was low and also stable. The combined effects of periodic thermocline breakdown, resulting in oxygen rich epilimnion waters mixing with hypolimnion waters, and the large volume of the hypolimnion resulted in a very small oxygen demand over time in these waters.

Table 18 presents results of oxygen demands for lakes in several different trophic ranges according to calculations by Hutchinson and Mortimer (Hutchinson, 1957). Oxygen demands are also shown for the Central Basin of Lake Erie for both 1970 and 1973. When this information is compared with the results of the Eastern Basin investigation from 1973 to 1975 (Table 9) some apparent differences are noted. The Eastern Basin, unlike the Central Basin (Table 18), never experienced anoxic conditions over the three year study. Secondly, the Eastern Basin calculations were computed over a much longer time period than the Central Basin results. The larger hypolimnion volumes and greater total oxygen content in the Eastern Basin over a longer time period would continue to increase from the non-limiting quantities of oxygen available. Therefore, only the shorter time period computations of the Eastern Basin oxygen demand are comparable to the Central Basin results and the classification of Hutchinson (Table 18). Besides not experiencing anoxia, the Eastern Basin has a much lower demand than the Central Basin and definitely fits the mesotrophic classification requirements of Hutchinson.

The algal biomass and its seasonal composition are summarized for the Eastern Basin from 1973-1975 in Table 11 and Figure 19. From these data it is apparent that the phytoflagellates contributed the least to the biomass composition on a yearly basis and only approached the numbers observed in 1970 by Munawar and Munawar (1976) in the summer of 1975. Additionally, in contrast to the 1970 results, diatoms were the major biomass component for the GLL's 1973-1975 observation.

The phytoplankton biomass for the three years ranged between 0.3 g/m^3 and 3.7 g/m^3. Previously, maximum peaks of 4.0 g/m^3 for phytoplankton biomass (Munawar and Munawar, 1976) in the Eastern Basin were reported. Therefore, the change in biomass range has been minimal and was possibly more of an artifact of sampling dates. According to Vollenweider (1968) a mesotrophic lake can be characterized by phytoplankton biomass concentration ranges of 3-5 g/m^3. Thus the Eastern Basin could be compared to a mesotrophic environment based both on the phytoplankton data and the calculated oxygen demands.

The apparent discrepancy between the 1970 results (Munawar and Munawar, 1976) and the results reported here for the phytoflagellates may be related to sampling. The GLL data were representative of the upper epilimnetic waters. It has been suggested that phytoflagellates are more mobile and could migrate into the hypolimnion. If this were the case, upper epilimnetic samples could have missed a large proportion of this group during many sampling periods.

The peak in primary productivity for the three years reported here for the Eastern Basin ranged from 16 to 20 mg C/m^3/day. These results are in close agreement with the data reported

Table 18. CLASSIFICATION AND CENTRAL BASIN COMPARISON OF OXYGEN DEMAND

General lacustrine classification according to oxygen demand

	Hutchinson	Mortimer
	millimoles/m^2/day	
Oligotrophic	<5.3	<7.7
Mesotrophic	5.3 - 10.3	7.7 - 17.2
Eutrophic	>10.3	>17.2

Previous oxygen demands calculated for the Central Basin of Lake Erie*

1970	(Burns and Ross, 1972)	12.23 for 26 days
1973	(The Ohio State Univ.)	11.90 for 44 days

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* For both time periods the hypolimnion encountered anoxic conditions

in 1970 (Munawar and Munawar, 1976). Chlorophyll-a concentrations were also similar between the two studies with maximum values reaching approximately 7 mg/m^3.

Very few relationships (significant correlations) were observed between the phytoplankton and the physio-chemical variables over the three year study. There are several possibilities that could explain in part the lack of correlation between such variables as biomass and nutrients. The most probable explanation is the fact that many of the scheduled sampling cruises over the three year duration missed the peak dynamics of many of the groups comprising the total phytoplankton biomass. Thus, the kinetics of growth and uptake of nutrients could not truly be explained and the expected relationships were not revealed. Furthermore, in a synoptic survey of the type described here, the higher concentrations of soluble nutrients and biomass found near river inputs contrasted with lower midlake levels. This tended to disrupt the expected biotic-abiotic relationships. Additionally, settling and turbulence processes could move the phytoplankton away from the water mass in which they actually grew (Munawar and Burns, 1976). The lack of correlation was probably a combination of several of the above explanations.

The results of this three year investigation illustrate that such parameters as chlorophyll and primary productivity are influenced by a number of different phytoplankton groups as well as growth controlling factors in a variety of ways. For example, the primary productivity and chlorophyll-a values were directly related to Chlorophyta during certain seasons of the year and at the same time inversely related to Chrysophyta. During different time periods other variables were related to primary productivity and chlorophyll-a. Consequently, to understand the true relationships that exist, a more intensive sampling schedule needs to be developed.

The Basinwide distribution of crustacean zooplankton indicated considerable horizontal and seasonal variation throughout the year. Due to the rapidly changing temporal abundances at any location, it was difficult to describe in any way but the most general terms how zooplankton were related to other variables in the Basin.

Patalas (1972) and Watson (1976) indicated that zooplankton populations peaked in late June which also were noted in this 1973-1975 study. Examination of the group compositions (Figure 22) indicated that the cladocerans had two peaks of activity, during early summer and again in the fall, while the cyclopoids dominated during the remainder of the year. The cyclopoids also dominated at the midlake stations and in the less eutrophic northern shore stations, while the cladocerans were more numerous at sites of river inputs and entrainment from the Central Basin (Figure 23). The general annual pattern for zooplankton over the three year study can be illustrated by a eutrophication index which is the ratio of calanoids to cyclopoids plus cladocerans (Patalas, 1972). Table 15 shows this index for each year and indicates a slight decrease represented by a movement towards less eutrophic conditions.

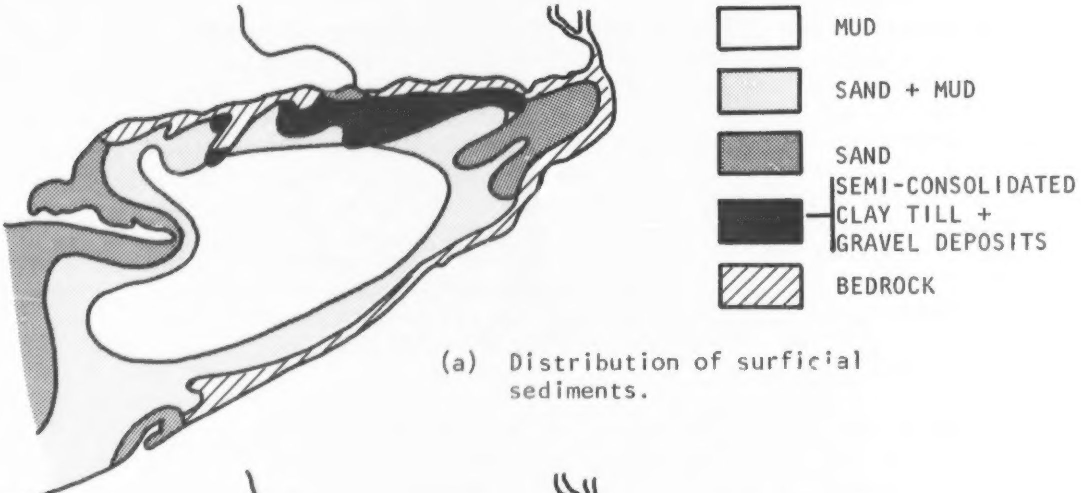
There were no strong relationships between the zooplankton groups and either primary productivity or chlorophyll-a. The cladocerans and cyclopoids did show an inverse relationship with total phytoplankton biomass, but more importantly the cladocerans showed a strong positive correlation with the nutrients of ammonia and total phosphorus. This is in close agreement with findings by Watson (1976) when he suggested that the cladocerans were responding to available food sources in the form of organic detritus rather than phytoplankton abundance. This would also partially explain the increase in total zooplankton for 1974 with the corresponding increases in ammonia and to a lesser degree phosphorus. It has been suggested that in the more eutrophic waters the detritus-zooplankton food chain is favored over the classical herbivore chain of more oligotrophic lakes (Gliwicz, 1969).

The preceding is further supported by the comparison of horizontal zooplankton distributions for each year (Figure 21) with ammonia and total phosphorus distributions (Figures 2 and 5). The higher concentrations of phosphorus and ammonia especially in the area of tributary inflows were accompanied by high zooplankton concentrations. These organically rich inputs probably provided impetus for heterotrophic bacterial growth (Watson, 1976) as well as a direct food source for the local masses of crustacean zooplankton. Additionally, because of the suggested detritivore habits for the cladocerans, the closer relationship seen between zooplankton and nutrient increases rather than between the phytoplankton biomass and these same nutrient changes can be explained.

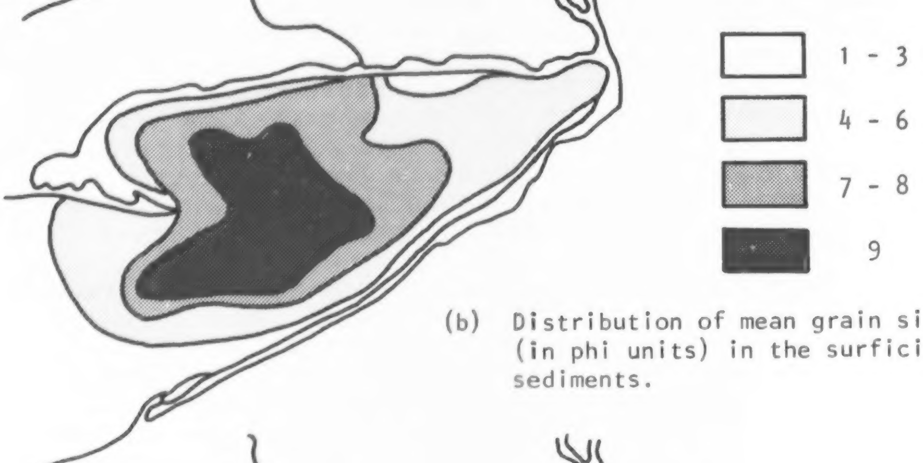
Very little information exists concerning the benthic communities of the Eastern Basin of Lake Erie. Therefore, the results obtained from the three year investigation reported here serves as a very important contribution to the baseline information for this component of the Eastern Basin system.

The Eastern Basin did not experience anoxia in any of the three years of the study. Consequently, oxygen conditions probably did not play a role in the benthic community distribution. The primary factors effecting spatial distribution within the Basin were probably sediment type and organic carbon content of the superficial sediments. Data obtained from Thomas et al. (1976) on these variables is presented in Figure 26.

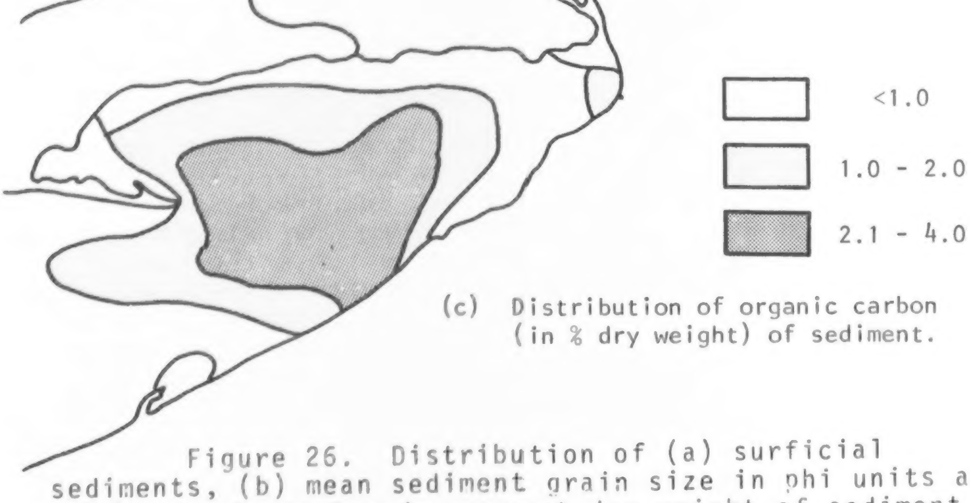
The midlake stations which were characterized by a much higher carbon content and superficial sediments composed primarily of mud and silt (median grain size 6-9 ϕ) supported community


MUD
SAND + MUD
SAND
SEMI-CONSOLIDATED CLAY TILL + GRAVEL DEPOSITS
BEDROCK

(a) Distribution of surficial sediments.



(b) Distribution of mean grain size (in phi units) in the surficial sediments.


<1.0
1.0 - 2.0
2.1 - 4.0

(c) Distribution of organic carbon (in % dry weight) of sediment.

Figure 26. Distribution of (a) surficial sediments, (b) mean sediment grain size in phi units and (c) organic carbon in percent dry weight of sediment. (From Thomas et al., 1970)

types dominated by oligochaetes and amphipods. *Stylodrilus* and *Limnodrilus* were the major oligochaetes; *Pontoporeia* was the dominant amphipod present. The eastern portion of the Basin, which showed the lowest carbon accumulation probably due to the higher amount of sand content of the sediment, displayed the dominance of a bivalve-oligochaete community type. The northern shore stations, because of the hard clay base and sandy sediments, supported communities comprised primarily of bivalves and amphipods. Again the carbon content of the sediment was low which further discouraged the presence of burrowing forms such as the worms. This type of environment was also characteristic of Stations 17, 20 and 21 which again showed the dominance of bivalves and amphipods.

Prior to this study, the most important oligochaetes within the Eastern Basin were *Stylodrilus* sp. and *Tubifex tubifex* (Cook and Johnson, 1974). The data presented here suggested that *Limnodrilus*, a species associated with the more eutrophic waters of the Western and Central Basins, within recent years had become established in greater numbers within the Eastern Basin. The chironomids that Cook and Johnson (1974) identified as being associated with the more oligotrophic waters of the Eastern Basin, on the other hand, were not encountered in large numbers over this study duration. The amphipods, especially *Pontoporeia* were still quite abundant as Cook and Johnson had also indicated.

Another comparison between Cook and Johnsons' results and the results of the study described here were in terms of total macroinvertebrate numbers encountered, Cook and Johnson's study illustrated that the mean number of organisms for the Eastern Basin was approximately $4600/m^2$. The present investigation showed a mean number of organisms of $8278/m^2$, an apparent two-fold increase. The range over the Eastern Basin by location was $1394/m^2$ near the Grand River to $29,138/m^2$ off of Long Point. These comparisons imply that the benthic environment has defintely changed in recent years to a more "eutrophic" type environment.

In summary, considering the preceding discussion on both the pelagic environment of the Eastern Basin, including the physio-chemical and biological variables, and the benthic communities represented within the Basin, two opposing trends can be identified. In general there has been very little change within the pelagic environment over the last five years with the exception of nitrogen. The nitrogen changes, however, were only identified for the first two years of this study and appeared to return to 1970 levels (Burns, 1976) during the 1975 sampling year. The other physio-chemical and biological variables were comparable to levels observed in 1970.

The benthic environment, on the other hand, displayed a definite shift from a more oligotrophic environment to characteristics typical of eutrophy between 1968 (data reported by Cook and Johnson, 1974) and the present study. There has been both an apparent increase in numbers of organisms as well as some species shifts to those more readily associated with highly productive environments. The one problem that arises in the comparison mentioned above is the lack of knowledge concerning the methods of collection and analysis of the 1968 data, the sampling time, and the number of sample sites within the Basin that produced the results quoted. This information may have a direct bearing on the comparisons made.

The changes in the benthic community with the lack of change within the water column tend to suggest that the midlake area of the Basin has displayed a relatively stable condition concerning nutrients and general productiveness over the past five years. The bottom waters and benthic habitat have received the majority of allochthonous inputs to the Basin over the years, causing the changes observed in the immediate vicinity of the superficial sediments. Additionally these sediments serve as a storage pool for excesses of many of the nutrients associated with eutrophication. Consequently, changes within the open waters of the Basin resulting from a decrease in nutrient loadings would be small and very difficult to measure because of the constant recycling of the nutrients from the sediment pools. On account of this large scale recycling, it would probably take many years of reduced loadings to realize a change in nutrient levels in the midlake region of the Eastern Basin.

The major goal of the GLL's three year study was to address the four objectives stated at the beginning of this document. The design of the project and the treatment of the resulting data has been carried out in light of these objectives.

The results obtained from the three year investigation definitely contribute a large amount of up-to-date baseline information to the general knowledge of Eastern Basin dynamics. Furthermore, this information agrees, in most instances, with data obtained from other studies within the past five years. The information obtained on all variables points to the premise that the Eastern Basin of Lake Erie can presently be characterized as a mesotrophic body of water that is in a relatively stable condition concerning nutrient dynamics and biological processes.

The second objective of the project, to identify problem areas within the Basin, resulted in the conclusion that most of the problem areas were associated with tributary inflows and entrainment from the Central Basin. Because the inflow effects were localized and short-lived, the majority of the midlake stations showed no real change. An alternative means of examining these local inputs would have been to investigate the littoral areas and shallow nearshore waters, an area much neglected in Lake Erie. The specific problem areas that were identified were the following: the waters offshore from the Grand River as well as areas west of this inflow (down-current stations); southern shore stations between Erie, Pa. and Dunkirk including the mouth of the Twenty Mile Creek all influenced by longshore currents moving in an easterly direction; and the eastern stations of the Basin due to the industrial influences of the area (Buffalo and Port Colborne). Another area of concern, the westerly midlake stations, primarily were influenced by entrainment processes from the Central Basin.

The benthic sampling program indicated that two areas were relatively discrete in the Basin. These areas were the bottom off of Dunkirk and the eastern benthic environment. Both locations, which were also identified in the preceding paragraph, were characterized by fewer numbers of organisms than the Basin mean and furthermore consisted of much higher percentages of oligochaetes than most other parts of the Basin.

The third objective is the one goal which probably cannot be completely met over the duration of the study described here. As mentioned previously, because of the extensive storage capacity of the Basin sediments and the high degree of recycling within the water column, a number of years of study are needed to accurately measure any changes that may occur from reduction of nutrient loadings to the Basin. Short term effects of local inputs are identifiable as shown from the nitrogen data collected in 1974. A study of such short duration, however, cannot measure changes in water quality from reduced loadings. Consequently, now that a baseline of data has been established for the Eastern Basin, the third objective can become the major focal point of all future work concerning the monitoring and surveillance program. Furthermore, a little more emphasis can also be placed on the nearshore waters and littoral areas of the Basin.

This project was also designed to determine the effectiveness of measuring a limited number of biotic and abiotic parameters in a synoptic fashion to evaluate eutrophication processes in a large lake. The results obtained over the three year study period indicated that in general the variables measured were appropriate to meet this objective with the exception of not measuring orthophosphorus, dissolved silica, and the two benthic variables of particle size and sediment organic carbon. In all future work, therefore, it is suggested that these variables be included.

The fact, however, remains that the variables that were measured, in many instances, did not provide the information intended because of the sampling schedules. For example, in 1975 most of the biological peaks were missed due to a lack of sampling during the peak periods. The problem, therefore, does not lie with the variables measured as much as it does with when these variables were measured.

Another point to emphasize concerning the fourth objective was the apparent duplication of information at a large number of the sampling stations. As illustrated in the results, there were discrete areas of the Basin which were characterized by unique physio-chemical processes. In most instances these areas were represented by a large number of sampling stations. At this point the appropriate approach may be to delete some of these duplicative stations as a trade off for: 1) increasing the cruise schedule; 2) performing a more rigorous sampling routine at a smaller number of stations (e.g. sample a decreased number of synoptic stations while increasing the rigor of sampling on one station from each of the discrete water masses described); 3) begin placing more emphasis upon the nearshore waters and littoral zone of the Basin.

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